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Chapter 5. Managing an Uncertain Future

About This Chapter

Chapter 5, "Managing an Uncertain Future," emphasizes the need for decision-makers, water and resource managers, and land use planners to use a range of considerations in planning for California's water future in the face of many uncertainties and risks. It provides examples of uncertainties and discusses the need to assess risks in planning for actions with more sustainable outcomes. An approach is presented for evaluating resource management strategies for robustness by using multiple future scenarios. Water management vulnerabilities identified during preparation of *California Water Plan Update 2013* (Update 2013) are presented. A framework is provided to measure the sustainability of water management policies and projects. This chapter describes the following topics:

- Recognizing and Planning for Risk and Uncertainty.
- Water Scenarios 2050: Possible Futures.
- Managing for Sustainability.
- Summary.

Recognizing and Planning for Risk and Uncertainty

Overview

California Water Plan Update 2009 (Update 2009) included a framework for improving water reliability through two initiatives. The first initiative places emphasis on integrated regional water management (IRWM) to make better use of local water sources by integrating multiple water and related resources, such as water quality, local and imported water supplies, watershed protection, wastewater treatment and water recycling, and protection of local ecosystems. The second initiative places emphasis on maintaining and improving statewide water management systems. These two initiatives form the foundation of the Update 2013 strategic plan to secure reliable and clean water supplies through 2050. The California Water Plan (CWP) acknowledges that planning for the future is uncertain and that change will continue to occur (see Box 5-1). Update 2013 builds on three key considerations in the planning approach for future management of regional and statewide water resources. The planning approach should (1) recognize and reduce uncertainties inherent in the system, (2) define and assess the risks that can hamper successful system management and select management practices that reduce the risks to acceptable levels, and (3) keep an eye toward approaches that help implement and maintain water and flood management systems that have more sustainable outcomes.

PLACEHOLDER Box 5-1 Uncertainty, Risk, and Sustainability

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

Traditional Planning Approach — The Past is a Model for the Future

Water managers recognize the variable nature of waterflow in California's streams and rivers during wet and dry periods spanning from seasons to multiple years. Having too little water or too much water — droughts or floods — were often primary reasons that Californians built early water projects. Early in California's water development history, personal observations, and experience were often used to help size water facilities because of the limited availability of recorded data.

A system to record waterflow conditions over time gradually improved information available to water managers. However, the main assumption governing water planning and management for much of California's history has been that past records were a good indication of the frequency, duration, and severity of future floods and droughts, and these records were used as predictors of potential future conditions. In addition, historical records were generally used to establish trends, such as population growth, which were assumed to continue into the future.

This static view of the range of possible future conditions based on past records worked fairly well when the demands on the resources were considerably lower than now. Early designers of water facilities may have understood the variability of storm events and the range of streamflows that could occur and the likelihood that a reservoir would refill in a given year, but generally they did not fully understand or consider the interrelationships among ecosystem functions, flood management, water availability, water use, and water quality.

The past approach to flood planning focused on flood damage reduction and public safety. Projects were designed to control and capture flood flows by using facilities such as dams, levee systems, bypasses, and channel enlargements. Although these projects provided significant flood protection benefits, some of these early structural projects caused unintended consequences of higher peak flows, conflicts with environmental resources, and increased flood risks. These experiences have prompted flood planners to look more comprehensively at flood systems to gain a better understanding of floodplains, related water supply, and environmental systems to provide multiple benefits.

In addition, risks posed by earthquakes, extreme floods, and extreme droughts were generally underestimated. Without a complete acknowledgment of the uncertainties inherent in the system and the risks that the system actually faced, management was relatively simple compared with today's standards. Conditions appeared more certain and less risky than they actually were, and water managers were more focused on meeting shorter term objectives. Although understanding the past is still an important part of managing for the future, it is becoming increasingly apparent that continued management under this traditional approach will not provide for sustainable water resources into the future.

New Planning Approach — Anticipate Change

Today, as part of IRWM and integrated flood management, California's water and resource managers must recognize that conditions are changing and will continue to change. Traditional approaches for predicting the future based solely on projecting past trends will no longer work. Today, there is better recognition that strategies for future water management must be dynamic, adaptive, and durable. In addition, the strategies must be comprehensive and integrate physical, biological, and social sciences, as well as consider risk and uncertainty.

California's water management system is large and complex with decentralized water governance that requires a great deal of cooperation and collaboration among decision-makers at the State, federal, tribal, regional, and local level. California lacks a common analytical framework and approach to understand and manage the system, especially when management actions may compete for the same resources. Water managers must make sound investments that balance risk with reward, given today's uncertainties and those that may occur in the future. Update 2013 works to strengthen alignment between water managers while considering investment in innovation and infrastructure with multiple benefits.

As described in more detail in Chapter 6, "Integrated Data and Analysis: Informed and Transparent Decision Making," the CWP promotes ways to develop a common approach for data standards and for understanding, evaluating, and improving regional and statewide water management systems, and for common ways to evaluate and select from alternative management strategies and projects. DWR has initiated work on the Water Planning Information Exchange (Water PIE). This system for accessing and sharing data across existing networked databases will use Web services and Geographic Information System (GIS) software to improve analytical capabilities, develop timely surveys of statewide land use and water use, and estimates of future implementation of resource management strategies. Ultimately, Water PIE will build on, complement, and connect several existing data-sharing sites managed by DWR, including the Water Data Library, California Data Exchange Center, and the California Irrigation Management Information System.

Update 2013 acknowledges that planning for the future is uncertain and that change will continue to occur. It is not possible to know for certain how population growth, land use decisions, water demand patterns, environmental conditions, climate, and many other factors that affect water use, supply, and flood management may change by 2050. To anticipate change, water management and planning for the future needs to consider and quantify uncertainty, risk, and sustainability.

- **Uncertainty.** How water demands will change in the future, how ecosystem health will respond to human use of water resources, what disasters may disrupt the water system, and how climate change may affect water availability, water use, water quality, flooding, and the ecosystem are just a few uncertainties that must be considered. The goal is to anticipate and reduce future uncertainties, and to develop water management strategies that will perform well despite uncertainty about the future.

  Uncertainties will never be eliminated, but better data collection and management and improved analytical tools will allow water and resource managers to better understand risks within the system. Many water agencies in California have begun incorporating climate change information into their operation and planning process to reduce uncertainty of how climate may affect California's water resources in the future. Additional efforts are needed to develop the accurate climate data needed to reduce uncertainty and risk in California water management in the future. To read more about the development of DWR's Climate Science program, see in Volume 4, *Reference Guide*, the article "The State of Climate Change Science for Water Resources Operation, Planning, and Management," and visit http://www.water.ca.gov/climatechange.

- **Risks.** Uncertainties about future conditions contribute to water-related risks. Each future event has a certain, but unknown, chance of occurring and a set of consequences should it occur. Combining the likelihoods with consequences yields estimates of risk. For example, a chance of a levee failure with a certain-size flood event can be estimated with associated economic and human consequences. Likewise, one can estimate the likelihood of a drought of a specific severity and combine this with estimates of the consequences.

By reducing the uncertainties described above, the “true” risks can be reduced. State government and other entities are performing risk assessments that can be used in future planning to balance risk with reward when implementing new management actions. Risk assessments are also a way to quantitatively consider the uncertainties that relate to events of interest, such as the performance of levees, the consequences of flooding, and the impact of events on the environment. More information on these risk assessments can be found later in this chapter.

- **Sustainability.** Given the uncertainties and risks in the water system, one set of management strategies may provide for more sustainable water supply, flood management, and ecosystems than another set of management strategies. Water management must be dynamic, adaptive, and durable. As described later in this chapter, DWR has developed a draft framework for quantifying indicators of water sustainability and has begun testing the indicators in regional pilot studies.

Recognizing and Reducing Uncertainty

There are two broad types of uncertainty:

1. The first type of uncertainty comes from the inherent randomness of events in nature, such as the occurrence of an earthquake or a flood. However, additional data may allow better quantification of this uncertainty.
2. The second type of uncertainty can be attributed to lack of knowledge or scientific understanding. In principle, this uncertainty can be reduced with improved knowledge that comes from collection of additional information.

Although it is not necessary to categorize uncertainty for Update 2013 into these two types of uncertainty, it is important to consider these while improving data collection and analytical tools.

California’s water and resource managers must deal with a broad range of uncertainty. Uncertainty is inherent in the existing system and in all changes that may occur in the future. For example, although water managers can be certain that the flows in California’s rivers will be different next year compared with this year, they do not know the exact magnitude or timing of those changes. The threat of a chemical spill that may disrupt water diversion presents uncertainty. Future protections for endangered species may require modifications in water operation procedures that are unknown today. Scientists are trying to understand the reasons for the pelagic fish decline in the Sacramento-San Joaquin Delta (Delta), the condition of levees throughout the state, and the extent of groundwater recharge and overdraft, to name just a few of the uncertainties that need to be addressed in planning for the future.

For the purposes of considering potential changes and their inherent uncertainties, it is useful to consider and estimate how change may occur, gradual changes over the long term and more rapid or sudden changes over the short term. Gradual changes can include such factors as variation in population by region, shifts in the types and amount of crops grown in an area, or changes in precipitation patterns or sea level rise. Sudden changes can include episodic events, such as earthquakes, floods, droughts, equipment failures, chemical spills, or intentional acts of destruction. The nature of these changes, the uncertainties about their occurrence, and their potential impacts on water management systems can greatly influence the response to the changes. Box 5-2 shows some sources of future change and uncertainty.

PLACEHOLDER Box 5-2 Sources of Future Change and Uncertainty

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

With improved understanding of uncertainties, risks facing future operation of the system can be better assessed. Most risks originate from such hazards as floods, earthquakes, and droughts. But risks can also result from other issues, such as water demands growing faster than anticipated, salt water intrusion, or land subsidence caused by groundwater overdraft. Risk can be defined as the probability that a range of undesirable events will occur, which is usually linked with a description of the corresponding consequences of those events. Box 5-3 describes how risk management is an integral part of flood management. A range of tools is available for assessing and accounting for risk (see in Volume 4, *Reference Guide*, the article "Accounting for Risk").

PLACEHOLDER Box 5-3 Managing Floods vs. Managing Flood Risk

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There is no way of predicting the future with absolute certainty, but scenarios of possible future conditions can be constructed. Update 2013 considers many alternative, plausible, yet very different future scenarios as a way to consider uncertainty and risk and improve resource sustainability. For example, three alternative population growth rates and three alternative assumptions about future land-use development density are considered, thus yielding nine alternative growth scenarios. Many alternative scenarios of future climate are considered in order to represent extended droughts and climate change. The concept is not to plan for any one given future, but to identify strategies that are robust across many scenarios. Certain combinations of management strategies may prove to be robust regardless of the future conditions. This is especially true if the strategies have a degree of adaptability to differing conditions that may develop. A general description of the scenarios can be found later in this chapter.

Water Scenarios 2050: Possible Futures

Since *California Water Plan Update 2005* (Update 2005), the CWP has used the concept of multiple future scenarios to capture a broad range of uncertain factors that affect water management, but over which water managers have little control. Scenarios are used to test the robustness of strategies by evaluating how well strategies perform across a wide range of possible future conditions. The CWP organizes scenarios around themes of population growth, land use patterns, and climate change. Growth scenarios characterize a range of uncertainty surrounding how cities and other land managers will accommodate future population growth through infill development or expansion into areas of existing open space and agriculture. Climate scenarios explore how future climate change might influence timing, distribution, and amount of precipitation, storm runoff, and water supply.

Growth Scenarios

Future water demand is affected by a number of growth and land use factors, such as population growth, planting decisions by farmers, and size and type of urban landscapes. The CWP quantifies several factors that together provide a description of future growth and how growth could affect water demand for the urban, agricultural, and environmental sectors. Growth factors are varied between the scenarios to describe some of the uncertainty faced by water managers. For example, it is impossible to predict future population growth accurately, so the CWP uses three different but plausible population growth estimates when determining future urban water demands. In addition, the CWP considers up to three different alternative views of future development density. Population growth and development density will reflect how large the urban landscape will become in 2050 and are used by the CWP to quantify encroachment into agricultural lands by 2050. Table 5-1 identifies the growth scenarios relative to current trends by using information from the California Department of Finance and the Public Policy Institute of California.

PLACEHOLDER Table 5-1 Conceptual Growth Scenarios

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

For Update 2013, DWR worked with researchers at the University of California, Davis, to quantify how California might grow through 2050. The UPlan model was used to estimate a year 2050 urban footprint under the scenarios of alternative population growth and development density listed in Table 5-1 (see http://ice.ucdavis.edu/project/uplan for information on the UPlan model). UPlan is a simple rule-based urban growth model intended for regional or county-level modeling. The needed space for each land use type is calculated from simple demographics and is assigned based on the net attractiveness of locations to that land use (based on user input), locations unsuitable for any development, and a general plan that determines where specific types of development are permitted. Table 5-2 describes the amount of land devoted to urban use for 2006 and 2050, and the change in the urban footprint for California under each scenario. Table 5-3 describes how future urban growth could affect the land devoted to agriculture in 2050. Irrigated land area is the total agricultural footprint. Irrigated crop area is the cumulative area of agriculture, including multi-crop area, where more than one crop is planted and harvested each year. Each of the growth scenarios shows a decline in irrigated acreage over existing conditions, but to varying degrees.

PLACEHOLDER Table 5-2 Growth Scenarios (Urban) — Statewide Values

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PLACEHOLDER Table 5-3 Growth Scenarios (Agriculture) — Statewide Values

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Climate Scenarios

A significant improvement to the CWP scenarios in Update 2013 is a quantitative look at the uncertainty surrounding future climate change when evaluating the performance of new resource management strategies. After consultation with its Climate Change Technical Advisory Group, DWR chose to include 27 alternative climate scenarios in the evaluation of future strategies. These include 12 climate scenarios identified by the Governor's Climate Action Team (CAT) for future climate change, five scenarios repeating historical climate, five scenarios repeating historical climate with a severe 3-year drought, and five scenarios repeating historical climate with a warming temperature trend. Each of the climate scenarios has separate estimates of future precipitation and temperature. Collectively these estimates provide planners with a range of precipitation and temperature that might be experienced in the future, and they are used with other factors to estimate future water demands. Refer to Volume 4, *Reference Guide*, the article "Overview of Climate-Change Scenarios Being Analyzed," for additional information on the CAT climate scenarios.

Figures 5-1, 5-2, 5-3, and 5-4 show the variation in 30-year running average annual precipitation for locations in the Central Valley and Sierra Nevada foothill regions for the 1915-2003 historical period and U.S. Bureau of Reclamation scenarios of future climate, as well as 2011-2099 for the 12 CAT scenarios of future climate. The variation in the 30-year running average precipitation is represented as a box plot (also known as a box-and-whisker diagram or plot), which is a convenient way of graphically summarizing groups of numerical data using five numbers (the smallest observation, lower quartile [Q1], median [Q2], upper quartile [Q3], and largest observation). For example, for the historical period, the box plot for Red Bluff shows a minimum value of about 20 inches in the driest 30-year period and a maximum value of slightly over 23 inches in the wettest 30-year period. The precipitation values used to generate the box plots are from a specific point in each location.

PLACEHOLDER Figure 5-1 Variation in 30-Year Running Average Precipitation for Historical Record (1915-2003) and Alternative Scenarios of Future Simulated Climate (2011-2099) for Red Bluff

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

PLACEHOLDER Figure 5-2 Variation in 30-Year Running Average precipitation for Historical Record (1915-2003) and Alternative Scenarios of Future Simulated Climate (2011-2099) for Oroville

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

PLACEHOLDER Figure 5-3 Variation in 30-Year Running Average Precipitation for Historical Record (1915-2003) and Alternative Scenarios of Future Simulated Climate (2011-2099) for Fresno

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

PLACEHOLDER Figure 5-4 Variation in 30-Year Running Average Precipitation for Historical Record (1915-2003) and Alternative Scenarios of Future Simulated Climate (2011-2099) for Millerton

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Figure 5-5 shows the trend in the change in average annual temperature for the Sacramento Valley floor for each climate sequence compared with the 1951-2005 historical average. A distinct upward trend in temperature change is shown in each climate scenario. However, there is considerable year-to-year fluctuation and different expectations for the long-term magnitude of temperature change. While the absolute change in temperature varies from region to region, the relative change in average annual temperature follows a pattern similar in all regions to that shown for the Sacramento River Hydrologic Region in Figure 5-5.

PLACEHOLDER Figure 5-5 Change in Average Annual Temperature from Historical 1951-2005 Average for Historical Period and 12 Scenarios of Future Climate Years 2006-2100 for Sacramento Valley Floor

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Future Environmental Requirements

The CWP uses currently unmet environmental objectives as a surrogate to estimate new requirements that may be enacted in the future to protect the environment or new ecosystem restoration actions implemented, for example, under an IRWM plan. These unmet objectives are instream flow needs or additional deliveries to managed wetlands that have been identified by regulatory agencies or by pending court decisions, but which are not yet required by law. For Update 2013, the CWP has identified the following unmet objectives:

- American (Nimbus) Department of Fish and Wildlife Values.
- Stanislaus (Goodwin).
- Ecosystem Restoration Program #1, Delta Flow Objective.
- Ecosystem Restoration Program #2, Delta Flow Objective.
- Ecosystem Restoration Program #4, Freeport.
- Trinity below Lewiston.
- Ecosystem Restoration Program #3 San Joaquin River at Vernalis.
- San Joaquin River below Friant.
- Level 4 Water Deliveries to Wildlife Refuges.

The analysis of Response Packages, described below, includes assessments of these additional objectives. These are only some of the unmet objectives in the state. In particular, they do not include additional water to protect species in the Delta as recommended in the December 2008 Delta Smelt Biological Opinion issued by the U.S. Fish and Wildlife Service or to protect salmon and several other species as recommended in from the June 2009 Biological Opinion on the Central Valley Water Project by the National Marine Fisheries Service.

Evaluating Vulnerabilities and Resource Management Strategies for Three Hydrologic Regions

Throughout development of Update 2013, DWR has worked with the Statewide Water Analysis Network (SWAN) to develop methods to regionally evaluate and quantify the costs, benefits, and tradeoffs of different resource management strategies through the application of the Water Evaluation and Planning (WEAP) modeling platform. SWAN serves as the technical advisory committee for the CWP. The CWP is testing the evaluation methods by focusing on the three hydrologic regions in the Central Valley: the Sacramento River, San Joaquin River, and Tulare Lake Hydrologic Regions (see Figure 5-6). (See Volume 4, *Reference Guide*, the article "Evaluating Response Packages for the California Water Plan Update 2013, Plan of Study.")

PLACEHOLDER Figure 5-6 California's Hydrologic Regions Highlighting Three Central Valley Regions Used in Test Case

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This analysis of vulnerabilities and response packages uses Robust Decision Making (RDM), a quantitative decision support methodology designed to facilitate decisions under conditions of deep uncertainty (Lempert et al. 2003; Groves and Lempert 2007). Deep uncertainty occurs when the parties to a decision do not know — or agree on — the best model for relating actions to consequences or the likelihood of future events. RDM rests on a simple concept. Rather than using models and data to describe a best-estimate future, RDM runs models over hundreds to thousands of different sets of assumptions to describe how plans perform in many plausible futures. This information is used as part of a vulnerability analysis to identify which future conditions could result in the management decisions not achieving their objectives. RDM informs a tradeoff analysis, in which different decisions are compared based on their ability to reduce vulnerabilities, their costs, and other effects. (For more information about RDM, visit www.rand.org/topics/robust-decision-making.html.) Figure 5-7 shows the key steps of an RDM analysis.

PLACEHOLDER Figure 5-7 Robust Decision-Making Steps Used in Water Plan Analysis

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

The CWP is using this RDM framework to first evaluate the vulnerability of the current management system in the Central Valley (Steps 1-3 in Figure 5-7) and then compare how different water management response packages could improve the resilience of the system (Steps 1-4 in Figure 5-7). Specifically, the vulnerability analysis explores how well the Central Valley water management system would perform under a wide range of futures defined by the growth and climate scenarios described above. System performance is evaluated with respect to urban and agricultural unmet demand, unmet instream flow requirements and objectives, and groundwater levels. Performance of the water management system is evaluated under a number of alternative scenarios reflecting future population growth, changes to irrigated land area, and future climate variability.

The CWP is testing methods to regionally quantify and evaluate the costs, benefits, and tradeoffs of different resource management strategies through the application of the WEAP modeling platform. The Central Valley WEAP application (see Box 5-4) was applied over a large set of growth and climate scenarios. For each scenario, an assessment of water supply, demand, and unmet demand in the urban and agricultural sectors was performed. The model also reported on changes in groundwater and how frequently instream flow requirements were met. Figures 5-8 and 5-9 show agricultural supply demand and unmet demand results of a single simulation (out of many) performed for the Sacramento River Hydrologic Region and the San Joaquin and Tulare Lake hydrologic regions, respectively. This simulation is based on historical supply conditions and Current Trends population and urban density scenarios. The results presented below demonstrate the broad vulnerabilities faced by the three hydrologic regions evaluated. They are not sufficiently detailed for planning and decision-making at a scale finer than the hydrologic region.

PLACEHOLDER Box 5-4 Central Valley WEAP Model

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

In the Sacramento River Hydrologic Region, demand is highly variable and declines slightly over time as urbanization reduces irrigated land area. Supply largely meets demand, except for simulated years 2023 and 2024, which corresponds to a repeat of 1976-1977 drought conditions. In the San Joaquin River and Tulare Lake hydrologic regions, the model projects significant unmet demands. Shortages are particularly acute under the dry conditions of 1977 and the early 1990s. These results are consistent with the greater water supply constraints present in these regions today.

PLACEHOLDER Figure 5-8 Single Simulation of Agricultural Supply, Demand, and Unmet Demand for the Sacramento River Hydrologic Region

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

PLACEHOLDER Figure 5-9 Single Simulation of Agricultural Supply, Demand, and Unmet Demand for the San Joaquin River and Tulare Lake Hydrologic Regions

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Reliability, defined as the percentage of years in which demand is sufficiently met by supply, is one of several different ways the CWP summarizes the projections of future urban and agricultural conditions. Figure 5-10 shows the range of reliability results for both sectors in the Sacramento River and in the San Joaquin River and Tulare Lake hydrologic regions. In the figure, each dot indicates the reliability for one of 128 simulations (the results shown reflect a subset of all 243 futures evaluated). The vertical lines indicate the median of each distribution, and the shaded areas indicate the results that fall within the middle half of the distribution (between the 25th and 75th percentiles). The figure clearly shows that both the urban and agricultural sectors in the Sacramento River Hydrologic Region are projected to remain highly reliable across the futures evaluated. The urban reliability for the San Joaquin River and Tulare Lake hydrologic regions is less than 90 percent in only about 10 percent of the future scenarios. For the agricultural sector, reliability is broadly lower, with a median result of about 78 percent reliability. In some futures, reliability falls below 50 percent.

PLACEHOLDER Figure 5-10 Range of Urban and Agricultural Reliability Results Across Futures

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

Figure 5-11 shows results for how groundwater storage would change in the Sacramento River Hydrologic Region and San Joaquin and Tulare Lake hydrologic regions for each of the futures evaluated. In the Sacramento River Hydrologic Region, more than half the futures lead to increases in groundwater levels. This is caused by climate scenarios that are wetter than historical averages and reduced agricultural water use resulting from urbanization of agricultural lands. In the south of the Delta, more than 75 percent of the futures show declining groundwater levels.

PLACEHOLDER Figure 5-11 Range of Groundwater Storage Changes Across Futures

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Figure 5-12 shows how the reliability for six instream flow requirements varies across the futures. For four of the six — those located in the northern portion of the Central Valley region — the requirements are always met. The reliability for the Merced and Friant instream flow requirements, however, are less than 100 percent in most futures.

PLACEHOLDER Figure 5-12 Range of Instream Flow Requirement Reliability Across Futures

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The CWP next evaluated which future conditions would lead to low reliability in the San Joaquin and Tulare Lake hydrologic regions. Using statistical analysis, the CWP identified that the two most important factors driving low reliability outcomes are futures with high temperature and low precipitation in future decades. The specific growth scenarios (variations in population and land use density) are of secondary importance.

For the urban sector, reliability is less than 95 percent in about half of the futures. Figures 5-13 and 5-14 show these results graphed against the temperature trend (vertical axis) and change from historical precipitation levels (horizontal axis) of each simulation for two bounding land use scenarios — low population growth/high land-use density (Figure 5-13) and high population/low density (Figure 5-14). In these graphs, red X's are those results that are less than 95-percent reliable and green circles are those that are more than 95-percent reliable. For the low population growth/high-density land use scenario, four of the five low reliability results correspond to the climate scenarios in which temperature is greater than the 65 degrees and precipitation declines more than 13 percent from historical levels (Figure 5-13).

PLACEHOLDER Figure 5-13 Climate Conditions Leading to Low Urban Reliability in the San Joaquin River and Tulare Lake Hydrologic Regions for the Low-Population and High-Density Land Use Scenario

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The sensitivity of urban reliability to climate, however, increases significantly under the land use scenario in which population is high and density is low (Figure 5-14). For these futures, nine of the 22 climate scenarios are low reliability. The climate conditions consistent with these low reliability outcomes is much broader — warmer than 65 degrees but including any negative temperature trend (specifically, less than a 2 percent increase).

PLACEHOLDER Figure 5-14 Climate Conditions in the San Joaquin River and Tulare Lake Hydrologic Regions Leading to Low Urban Water Reliability for the High-Population and Low-Density Land Use Scenario for Three Sets of Climate Scenarios

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In the agricultural sector for the San Joaquin River and Tulare Lake hydrologic regions, almost all futures are low reliability (less than 95 percent). Figure 5-15 shows results for the current trends population and density land-use scenarios. In this graphic, as all but one result is low reliability, notice how reliability generally declines in warmer and dryer climate conditions (upper left). The warmest and driest climate conditions lead to reliability below 50 percent. These results clearly indicate that the agricultural sector within the San Joaquin River and Tulare Lake hydrologic regions will likely continue to experience low supply reliability, and perhaps extreme reliability problems, without additional water management strategies.

PLACEHOLDER Figure 5-15 Climate Conditions Leading to Low Agricultural Reliability Results in the San Joaquin River and Tulare Lake Hydrologic Regions

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In summary, the Sacramento River Hydrologic Region is projected to remain highly reliable with stable groundwater storage levels in most futures evaluated — even under alternative climate change projections. In the combined results for the San Joaquin River and Tulare Lake regions, however, significant shortages occur. In the urban sector, reliability is below 95 percent in many futures, particularly those with warmer and drier conditions, as well as high population growth and low land-use density. For the agricultural sector, reliability is consistently below 95 percent and can be lower than 50 percent in the hottest and driest climate scenarios.

Evaluation of Management Response Packages

The CWP is evaluating how implementing alternative mixes of resource management strategies could reduce the Central Valley vulnerabilities described above. Management response packages are each comprised of a mix of resource management strategies selected from Volume 3 and implemented at investment levels and locations, as described in the Plan of Study (see Volume 4, *Reference Guide,* the article "Evaluating Response Packages for the California Water Plan Update 2013, Plan of Study"). The focus of this analysis will be on the Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions, and will include strategies that are regionally significant. For example, a response package could include improvements in urban water-use efficiency that is expected to increase to 20 percent savings by 2020, additional groundwater storage, or increasing water for ecosystem restoration.

These response packages do not represent a definitive set of alternatives; instead, they illustrate different levels of strategy diversification that could be taken to address water management challenges. Table 5-4 describes the six response packages that are currently being evaluated. They are designed to incrementally increase in diversification in each subsequent diversification level. The first two add strategies that can be implemented locally, such as water use efficiency, and that require some regional coordination and infrastructure investment, such as conjunctive management and recycled municipal water. Diversification Levels 3-6 all include additional strategies designed to meet new instream flow targets and lead to the recovery of the region's groundwater basins. Diversification Level 4 seeks to maximize water use efficiency and includes the final two strategies, which involve one or two reservoirs — north of Delta and north and south of Delta, respectively.

PLACEHOLDER Table 5-4 Resource Management Strategies Used in Plan of Study

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

Figure 5-16 shows how the consideration of cost or level of effort can define a tradeoff, drawn from the proof-of-concept analysis developed for the CWP (Groves and Bloom 2013). The figure plots each response package by reduction in vulnerability (vertical axis) and level of effort (horizontal axis). In this analysis, the more-effective response packages cost more. However, additional efforts beyond the Increased Efficiency response package do not further reduce vulnerabilities. Thus, Increased Efficiency is always preferable to Moderate Increases or Aggressive Infrastructure. The line on the graph traces out a simple trade-off curve that could be considered when choosing among strategies.

PLACEHOLDER Figure 5-16 Tradeoff between Vulnerability Reduction and Cost of Example Response Packages from Proof-of-Concept Analysis

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

Statewide 2050 Water Demands

The section above described a vulnerability assessment for the Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions that was conducted to demonstrate application of RDM techniques. In this section a description is provided for how future statewide water demands might change under scenarios organized around themes of growth and climate change described earlier in this chapter. The change in water demand from 2006 to 2050 is estimated for each hydrologic region for agriculture and urban sectors under nine growth scenarios and 13 scenarios of future climate change. The climate change scenarios included the 12 CAT scenarios described earlier in this chapter and a 13th scenario representing a repeat of the historical climate (1962-2006) to evaluate a "without climate change" condition.

Figure 5-17 shows the change in statewide water demands for the urban and agricultural sectors under nine growth scenarios, with variation shown across 13 climate scenarios. The nine growth scenarios include three alternative population growth projections and three alternative urban land development densities, as shown in Table 5-1. The change in water demand is the difference between the historical average for 1998 to 2005 and future average for 2043 to 2050. Urban demand is the sum of indoor and outdoor water demand where indoor demand is assumed not to be affected by climate. Outdoor demand, however, depends on such climate factors as the amount of precipitation falling and the average air temperature. The solid blue dot in Figure 5-17 represents the change in water demand under a repeat of historical climate, while the open circles represent change in water demand under 12 scenarios of future climate change.

Urban demand increased under all nine growth scenarios consistent with population growth. On average, urban demand increased by about 3200 thousand acre-feet (taf) under the three low-population scenarios, 5300 taf under the three current-trend population scenarios, and about 9200 taf under the three high-population scenarios when compared with the historical average of 8200 taf. The results show that change in future urban water demands is less sensitive to housing density assumptions or climate change than to assumptions about future population growth.

Agricultural water demand decreases under all future scenarios owing to reduction in irrigated lands as a result of urbanization and background water conservation, when compared with historical average water demand of 30,200 taf. Under the three low-population scenarios, the average reduction in water demand was about 3,200 taf, while it was about 4,500 taf for the three high-population scenarios. For the three current trend population scenarios, this change was about 3,700 taf. The results show that low-density housing would result in more reduction in agricultural demand because more lands are lost under low-density housing than high-density housing.

PLACEHOLDER Figure 5-17 Change in Statewide Agricultural and Urban Water Demands for 117 Scenarios from 2006-2050 (million acre-feet per year)

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

Figure 5-18 shows the change in water demand for the agricultural and urban sectors for each of the 10 hydrologic regions. For each of the nine growth scenarios shown in Table 5-1, change in water demand was determined based on a repeat of a historical climate pattern and for 12 alternative scenarios of future climate change. It is evident from Figure 5-18 that future climate change presents a significant uncertainty with respect to future water demands. All regions show an increase in urban water demands and decrease in agricultural water demands. The South Coast is expected to have the greatest increase in urban water demands in response to population growth. Additional details about the regional water demands can be found in the Volume 2, *Regional Reports.*

PLACEHOLDER Figure 5-18 Change in Regional, Agricultural, and Urban Water Demands for 117 Scenarios from 2006-2050 (million acre-feet per year)

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

Limitations of Future Water Management Analysis for Update 2013

The analysis of resource management strategies developed for Update 2013 can allow comprehensive analysis of strategy performance when conducted at sufficient detail. However, all technical endeavors are subject to the limits of the particular technology being used and the financial resources available. Below are some of the important limitations the CWP team has identified for the analysis used for Update 2013.

- For Update 2013, DWR tested a vulnerability assessment for the Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions, which included an assessment of water supply, demand, and unmet demand in the urban and agricultural sectors. The analysis for the remaining seven hydrologic regions in California was coarser and focused on quantifying future water demands under alternative future scenarios.
- Many of the resource management strategies identified in Volume 3 can be represented in the Update 2013 application of WEAP, particularly those related to the water management objectives to reduce water demand, improve operational efficiency and transfers, and increase water supply. However, the analysis for Update 2013 had limited ability to none at all with regard to quantifying strategies that improve flood management, improve water quality, and practice resource stewardship. These will be considered as part of future enhancements to the CWP.
- The analysis for Update 2013 quantified some of the resource management strategy benefits for providing a supply benefit, improving drought preparedness, providing environmental benefits, improving operational flexibility and efficiency, and reducing groundwater overdraft. There was limited to no ability to quantify benefits for improving water quality, reducing flood impacts, energy benefits, and recreational opportunities. Quantifying these other benefits will be considered as part of future enhancements to the analytical framework.
- The analysis to support the CWP is designed to represent the water management system at sufficient detail to reflect important planning conditions, but not for detailed water project operations or to capture all detailed flows through the system. As a result, many system features, such as groundwater basins, are simplified to capture the broad regional behavior of groundwater recharge, groundwater storage, and hydrologic connection to rivers and lakes. Significant refinement in the analysis will be needed to support decisions by individual water districts.

Managing for Sustainability

With a growing recognition that California's water systems are over allocated — and faced with climate change, growing population, and more stringent environmental requirements — decision-makers, water managers, and planners are becoming increasingly aware of the need to both sustainably manage water and respond to changing availability and constraints on water. In Updates 2005 and 2009, the State refocused attention on the sustainability of California's water systems and ecosystems in light of current water management practices and expected future changes. A number of concurrent efforts are underway at the regional, State, and federal levels to manage natural resources more sustainably (see Volume 4, Reference Guide, the article "Examples of Managing for Sustainability," for more information). The California Water Sustainability Indicators Framework (Framework), developed as part of Update 2013, brings together water sustainability indicators that will provide information regarding water system conditions and their relationships to ecosystems, social systems, and economic systems. Figure 5-19 shows a conceptual representation of the Framework, and how communities interact to develop sustainability indicators using analytical information that ultimately is used to drive our water policy and to inform other end uses.

PLACEHOLDER Figure 5-19 Conceptual California Water Sustainability Indicators Framework

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

Sustainability indicators are qualitative or quantitative parameters from monitoring programs (e.g., streamflow) selected to represent parts of ecological, social, or economic systems. (See Volume 4, *Reference Guide,* the article "California Water Sustainability Indicators Framework.") The evaluation of the sustainability indicators reveals how our actions or inaction can degrade or improve conditions that lead to water sustainability. The Framework is built around statements of intent (e.g., objectives) and domains (e.g., water quality). Reporting indicator condition is based on the principle of measuring how far a current condition is from a desired condition. The Framework is intended to support reporting of conditions to a wide array of water and environmental stakeholders, the public, and decision-makers to build knowledge and to enhance adaptive decision-making and policy change. A detailed representation of the Framework is depicted in Figure 5-20, showing several steps involved with linking sustainability goals and objectives into public policy by using the most accurate sources of scientific information. Both the conceptual and detailed descriptions of the Framework highlight the cyclical and collaborative nature of efforts to develop sustainable policies.

PLACEHOLDER Figure 5-20 Details of the California Water Sustainability Indicators Framework

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

Goals and objectives are just one way to organize our thinking about an evaluation of sustainability. Another common approach is to evaluate progress within areas of concern or domains (e.g., ecosystem health). Five domains of natural and human systems are defined for the Framework (Table 5-5), which capture most of the environmental, social, and economic concerns about water sustainability — water supply reliability, water quality, ecosystem health, adaptive and sustainable management, and social benefits and equity.

PLACEHOLDER Table 5-5 Water Sustainability Domains

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

Explicit criteria must be used to select indicators to ensure that the resulting evaluation is robust and usable in decision-making. For Update 2013, about 80 candidate indicators were selected on the basis of the indicator selection criteria, from an extensive review of sustainability and water system indicators around the world and in California. This exercise resulted in a set of candidate indicators that efficiently covered the sustainability objectives, while also covering the five domains (e.g., water quality). The selected indicators are listed in Volume 4, *Reference Guide,* in Appendix D of the article "California Water Sustainability Indicators Framework."

Testing Sustainability Indicators with Pilot Studies

To assess the usefulness of the Framework for measuring water sustainability, it was tested at the state and regional scales. Draft sustainability goals and objectives were developed, based on Update 2009 objectives and resources management strategies. Indicators corresponding to the goals and objectives were chosen from the global literature and previous guidance in the CWP and other state planning documents. In the case of the state pilot, the sustainability goals and objectives, as well as the candidate indicators, were presented to various Update 2013 stakeholder forums, including the sustainability indicators interagency workgroup, State Agency Steering Committee, Public Advisory Committee, and Tribal Advisory Committee. The background, methods, results, and data downloads for the state and regional scale analyses are available at http://indicators.ucdavis.edu.

Statewide Pilot

Water sustainability indicators were evaluated at varying levels of specificity across the state, with the unit area of analysis depending on the specific indicator and data availability. For example, the water footprint and public perceptions of water management are measured at the state scale, whereas groundwater quality is measured at the well scale. Indicator evaluation included a conversion of the data to an equivalent sustainability score. The scores were calculated at the unit area of analysis, as well as being aggregated to each of the 10 hydrologic regions. The sections that follow include discussion of this analysis organized around the five water sustainability domains (see Table 5-5).

Water Footprint

A preliminary assessment has been conducted for California's Water Footprint. The Water Footprint can help identify water-related risks associated with California's consumption patterns. This risk results in part from the energy and hydraulic systems that distribute water, but also changing hydrologic and ecologic conditions in California and in places that produce goods and services consumed in the state. By demonstrating the degree to which our state has externalized its Water Footprint by importing water-intensive goods, the Water Footprint analysis may encourage State and regional water strategic plans to consider the vulnerability of water import dependency. The Water Footprint comprises three functions of water labeled by color: green water, blue water, and grey water. See Box 5-5 for additional information about the Water Footprint as an index of sustainability.

PLACEHOLDER Box 5-5 Water Footprint as an Index of Sustainability

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

The current assessment estimates that California's overall Water Footprint — a measure of the total volume of freshwater that is used to produce the goods and services consumed by Californians — is 65 million acre feet (maf) per year (Figure 5-21). This estimate represents the total amount of water used to support California's population and includes water for producing agricultural and industrial goods, and for residential, commercial, and institutional purposes. Nearly 30 percent of the total Water Footprint, or 20 maf, is associated with goods produced and consumed in California, which is referred to as California's Internal Water Footprint. About 70 percent of California's Water Footprint (45 maf) is associated with goods that are consumed in California but are produced outside of the state, which is referred to as California's External Water Footprint. The majority of California's External Water

Footprint relates to goods imported from other states and to a lesser degree from California's major foreign trading partners (e.g., Mexico, Canada, China).

PLACEHOLDER Figure 5-21 California's Blue and Green Water Footprint

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

Water Quality

Water Quality Index: There are many ways to measure water quality, including physical (e.g., temperature), chemical (e.g., pesticides), and biological (e.g., healthy algae communities) attributes. Water quality is affected by land and water development, as well as by natural processes. Land development leads to runoff of pollutants into local waterways and contributes to the degradation of water quality. One indicator of potential water quality is "impervious cover," which is the proportion of a watershed that has been covered by structures and related development. Streams in most hydrologic regions appear to have good water quality, based on runoff from developed areas (Figure 5-22). Streams in more urbanized regions are more likely to have moderate water quality scores. Averages at the hydrologic regions scale do not reflect local condition, which may vary from exceptionally good to very degraded. In addition, specific point sources of impacts on water quality from agricultural drainage, for example, are not captured in this approach.

PLACEHOLDER Figure 5-22 Water Quality Index Score for Hydrologic Regions

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

Ecosystem Health

Geomorphic Process: When land is developed, it changes stormwater runoff patterns and timing, constrains and modifies stream channels, and can exacerbate local and regional flooding. As is the case for water quality, impervious land cover is an indicator of land development that is useful for understanding modification of geomorphic processes. Streams in the urbanized San Francisco Bay and South Coast Regions are more likely to experience modified geomorphic processes than rural and undeveloped areas (Figure 5-23).

PLACEHOLDER Figure 5-23 Geomorphic Process Score for Hydrologic Regions

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

California Stream Condition Index: Aquatic ecosystems have many varying attributes and processes that can be used to indicate condition of the water body relative to standards of ecosystem health. One common attribute used as an index is the composition of fish and invertebrate communities, relative to historic or reference conditions. The California Stream Condition Index was developed by the State Water Resources Control Board (Mazor et al., in prep.), as a way to estimate aquatic ecosystem health. The index is based on the presence of aquatic invertebrates, which are sensitive to stream disturbance and pollution. The analysis shows that ecosystem health in most regions appears to be good, except in the urbanized San Francisco Bay and South Coast Regions (Figure 5-24).

PLACEHOLDER Figure 5-24 California Stream Condition Index Score by Site and for Hydrologic Regions

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

Native Fish Communities: Scientists have mapped the current and historic occurrence of most of California's native fish and many non-native fish (Moyle 2002; Santos et al. 2013). The ratio of current ranges to historic ranges was used to calculate a score for fish communities. The analysis shows that in the northern half of California, most fish communities have nearly all native species present. By contrast, in the agricultural Tulare Lake Basin, urban South Coast, and desert regions, many streams have few and sometimes no native fish species (Figure 5-25).

PLACEHOLDER Figure 5-25 Fish Community Score for Hydrologic Regions

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

Adaptive and Sustainable Management

Public Perception of Water Systems: The public expects clean and readily available water. Their expectation is usually that this public resource will be provided through State and local agencies, using public funds and based on policies that maintain the resource in trust. Measuring public understanding and support for water management and water policies is one proxy measure for how well State and local agencies are stewarding public trust resources. Three metrics were used to gauge public perceptions of current and future water supply management: (1) security of a region's water supply, (2) threat of climate change effects on water availability, and (3) appropriate management strategies to sustainably manage water systems in the future. The data were from surveys conducted by the Public Policy Institute of California (http://www.ppic.org/main/datadepot.asp).

Security of Water Supply: A little over one-third of respondents were very concerned about the current state of water supplies (Figure 5-26), and a similar proportion were concerned about water availability by 2019 (Figure 5-27), though these perceptions varied by region. A lower regional score is illustrative of a higher level of concern about water supply security for the region.

PLACEHOLDER Figure 5-26 Public Perception by Region of Threats to the Public Water Supply

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

PLACEHOLDER Figure 5-27 Public Perception of Security of Future Water Supplies

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

Threat of Climate Change Effects on Water Availability: At least half of the respondents have some level of concern about the effects on future water availability from droughts influenced by climate change (Figure 5-28). This perception varied only slightly by region. A lower regional score is illustrative of a higher level of concern about the threat of climate change in the region.

PLACEHOLDER Figure 5-28 Public Perception of Effects of Climate Change on Future Water Supplies

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

Future Sustainable Management of Water Systems: When asked about water management to meet future human needs, half of Californians favored managing and using existing supplies more efficiently (Figure 5-29). More than half of the people surveyed favored spending more money on improving conditions for native fish, with a third of the people favoring doing so even if their water bills went up (Figure 5-30).

PLACEHOLDER Figure 5-29 Public Perception of Future Water Management Strategies to Maintain Water Supply

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

PLACEHOLDER Figure 5-30 Public Favor for Improving Conditions for Fish, Including Payment Strategies

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

Social Benefits and Equity

Groundwater and Drinking Water Contamination: Water sustainability rests on the principle that people have equitable access to public trust resources such as water, and disparities in benefits and burdens are minimized. Accordingly, access to clean drinking water is a key component of water sustainability. In California, there are many contaminants that can and have made their way into groundwater, the primary drinking water source for the majority of Californians (State Water Resources Control Board 2013). Because contaminant concentrations can be reduced to levels below legal thresholds through mixing with cleaner source-waters and through treatment, most people drink clean water most of the time in California. The California Legislature passed Assembly Bill 2222 in 2008, requiring the State Water Resources Control Board to report to the Legislature on communities that rely on contaminated groundwater and principal contaminants in groundwater. Nitrate was identified as the most common groundwater contaminant originating from human activities and was found to be second overall after arsenic. Certain community water services rely exclusively on groundwater and have exceeded maximum contaminant levels (MCLs) for various contaminants at some time in the last 10 years. The presence of nitrates and the reliance on contaminated groundwater are two indicators that can be used to understand where in California groundwater is affected by contaminants. Regions of California vary in both the concentration of nitrates in groundwater and the community reliance on contaminated water (Figure 5-31). Inland and coastal agricultural regions have the highest number of communities reliant on contaminated groundwater exceeding the nitrate MCL of 45 milligrams per liter.

PLACEHOLDER Figure 5-31 Groundwater and Drinking Water Contamination Score for Hydrologic Regions

[Any draft tables, figures, and boxes that accompany this text for the public review draft are included at the end of the chapter.]

Regional Pilot

To test the Framework at the regional scale, the CWP considered a dozen potential pilot study areas. The Santa Ana Watershed Project Authority (SAWPA) was selected as a willing and able regional pilot partner because of their technical capacity and the fact that they were currently engaging a broad range of stakeholders in regional planning, through their One Water One Watershed 2.0 (OWOW2.0) process (visit http://www.sawpa.org/owow/). The OWOW2.0 process relies on "Pillars," which are stakeholder groups focusing on particular issues of regional importance, as well as on advisory committees of member water agencies. In partnership with SAWPA and the Council for Watershed Health, goals, objectives, and candidate indicators were developed to test the Framework and evaluate water sustainability for the regional pilot.

Summary

Integrated water management is the basis for California's water planning. This umbrella approach recommends that California and its regions consider how a portfolio of resource management strategies, as described in Volume 3, might meet multiple water management objectives in light of many risks and uncertainties and ensure sustainable use of water resources. DWR and other entities are conducting various risk assessments so that risks can be better balanced with the rewards for improved management. Update 2013 introduced a water sustainability indicators framework to ascertain how the objectives of the CWP, associated resource management strategies, and recommended actions would lead to sustainable water use and supply for the state and its 10 hydrologic regions.

Update 2013 evaluated how statewide and regional water demands might change by 2050 in response to uncertainties surrounding future population growth, land use changes, future climate change, and other factors. These future uncertainties will play out quite differently across the regions of California, so each region will need to choose and implement a portfolio of resource management strategies that consider regional water management challenges. Update 2013 also conducted a more comprehensive vulnerability analysis for the Sacramento River, San Joaquin River, and Tulare Lake regions to test longer term analytical enhancements for the CWP. This analysis tested different response packages, or combinations of resource management strategies, under many future uncertainties. These response packages help decision-makers, water managers, and planners develop and evaluate integrated water management plans that invest in actions with more sustainable outcomes.

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Table 5-1 Conceptual Growth Scenarios

Scenario	Population Growth	Development Density
LOP-HID	Lower than Current Trends	Higher than Current Trends
LOP-CTD	Lower than Current Trend	Current Trends
LOP-LOD	Lower than Current Trends)	Lower than Current Trends
CTP-HID	Current Trends	Higher than Current Trends
CTP-CTD	Current Trends	Current Trends
CTP-LOD	Current Trends	Lower than Current Trends
HIP-HID	Higher than Current Trends	Higher than Current Trends
HIP-CTD	Higher than Current Trends	Current Trends
HIP-LOD	Higher than Current Trends	Lower than Current Trends

Table 5-2 Growth Scenarios (Urban) — Statewide Values

Scenario	2050 Population (millions)	Population Change (millions) 2006[a] to 2050	Development Density	2050 Urban Footprint (million acres)	Urban Footprint Increase (million acres) 2006[b] to 2050
LOP-HID	43.9[c]	7.8	High	5.6	0.3
LOP-CTD	43.9	7.8	Current Trends	6.2	1.0
LOP-LOD	43.9	7.8	Low	6.5	1.2
CTP-HID	51.0[d]	14.9	High	6.3	1.1
CTP-CTD	51.0	14.9	Current Trends	6.7	1.5
CTP-LOD	51.0	14.9	Low	7.1	1.9
HIP-HID	69.4[e]	33.3	High	6.8	1.6
HIP-CTD	69.4	33.3	Current Trends	7.6	2.4
HIP-LOD	69.4	33.3	Low	8.3	3.1

Notes:

[a] 2006 population was 36.1 million.

[b] 2006 urban footprint was 5.2 million acres.

[c] Values modified by the California Department of Water Resources (DWR) from the Public Policy Institute of California.

[d] Values provided by the California Department of Finance.

[e] Values modified by DWR from the Public Policy Institute of California.

Table 5-3 Growth Scenarios (Agriculture) — Statewide Values

Scenario	2050 Irrigated Land Area[a] (million acres)	2050 Irrigated Crop Area[b] (million acres)	2050 Multiple Crop Area[c] (million acres)	Reduction in Irrigated Crop Area (million acres) 2006 to 2050
LOP-HID	8.6	9.2	0.65	0.1
LOP-CTD	8.4	9.0	0.63	0.3
LOP-LOD	8.3	8.9	0.63	0.4
CTP-HID	8.4	9.0	0.63	0.3
CTP-CTD	8.2	8.9	0.62	0.4
CTP-LOD	8.1	8.7	0.61	0.6
HIP-HID	8.2	8.9	0.62	0.4
HIP-CTD	8.0	8.6	0.60	0.7
HIP-LOD	7.8	8.4	0.58	0.9

Notes:

[a] 2006 Irrigated land area was estimated by the California Department of Water Resources (DWR) to be 8.7 million acres.

[b] 2006 Irrigated crop area was estimated by DWR to be 9.3 million acres.

[c] 2006 multiple crop area was estimated by DWR to be 0.65 million acres.

Table 5-4 Resource Management Strategies Used in Plan of Study

<table>
<tr><th rowspan="2">Response Package</th><th colspan="5">Resource Management Strategy Category</th></tr>
<tr><th>Environmental Flow Recovery Targets</th><th>Groundwater Recovery Targets</th><th>Water Use Efficiency</th><th>Recycled Municipal Water</th><th>Conjunctive Management</th></tr>
<tr><td>Currently Planned Management</td><td rowspan="3">Current</td><td rowspan="3">Groundwater levels cannot drop below Historical low</td><td>Urban: 20% by 2020</td><td rowspan="2">Current</td><td rowspan="2">Current</td></tr>
<tr><td>Diversification Level 1</td><td rowspan="3">Urban: 30% by 2030

Agriculture: 10% by 2020</td></tr>
<tr><td>Diversification Level 2</td><td rowspan="4">50% recycled water use by 2030</td><td rowspan="2">Maximum of 20 TAF/month per planning area to be banked (SOD) starting in 2020</td></tr>
<tr><td>Diversification Level 3</td><td rowspan="3">Sacramento River at Freeport

Stanislaus AFRP 2

ERP Target 1

ERP Target 2 (all by 2015)</td><td rowspan="3">Groundwater levels cannot drop below midpoint of 1970-2005 minimum and initial conditions (starting 2015)</td></tr>
<tr><td>Diversification Level 4</td><td>Urban: 30% by 2030; 35% by 2040

Agriculture: 10% by 2020; 15% by 2030</td><td rowspan="2">Maximum of 40 TAF/month per planning area to be banked (SOD) starting in 2020</td></tr>
<tr><td>Diversification Level 5</td><td>Urban: 30% by 2030; 40% by 2040

Agriculture: 10% by 2020; 20% by 2030</td></tr>
</table>

Table 5-5 Water Sustainability Domains

Domain Name	Description
Water Supply Reliability	The availability or provision of water of sufficient quantity and quality to meet water needs for health and economic well-being and functioning
Water Quality	The chemical and physical quality of water to meet ecosystem and drinking water standards and requirements
Ecosystem Health	The condition of natural system, including terrestrial systems interacting with aquatic systems through runoff pathways
Adaptive and Sustainable Management	A management system that can nimbly and appropriately respond to changing conditions and is equitable and representative of the various needs for water in California
Social Benefits and Equity	The health, economic, and equity benefits realized from a well-managed water system, including management of water withdrawal and water renewal

Figure 5-1 Variation in 30-Year Running Average Precipitation for Historical Record (1915-2003) and Alternative Scenarios of Future Simulated Climate (2011-2099) for Red Bluff

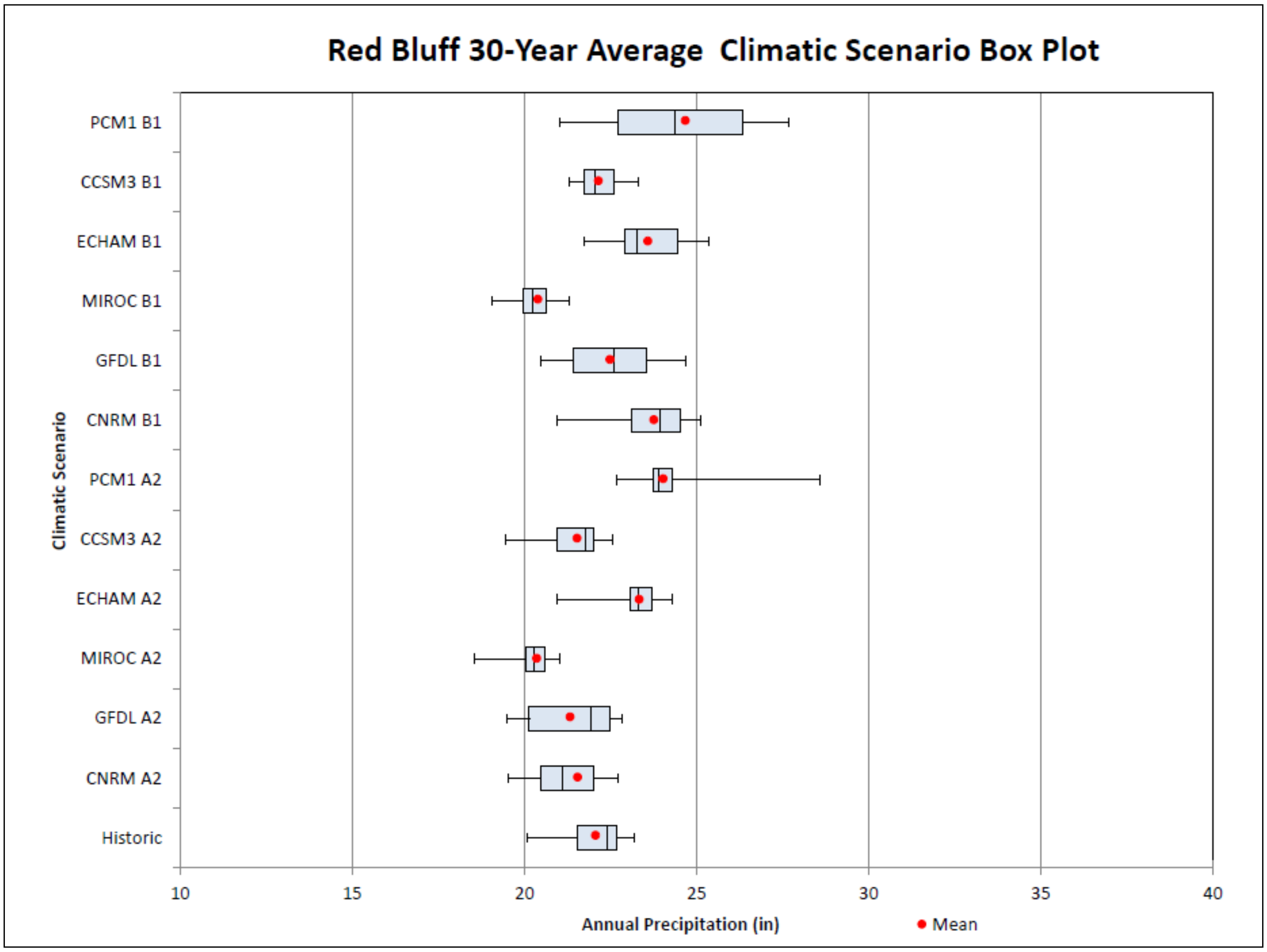


Figure 5-2 Variation in 30-Year Running Average Precipitation for Historical Record (1915-2003) and Alternative Scenarios of Future Simulated Climate (2011-2099) for Oroville

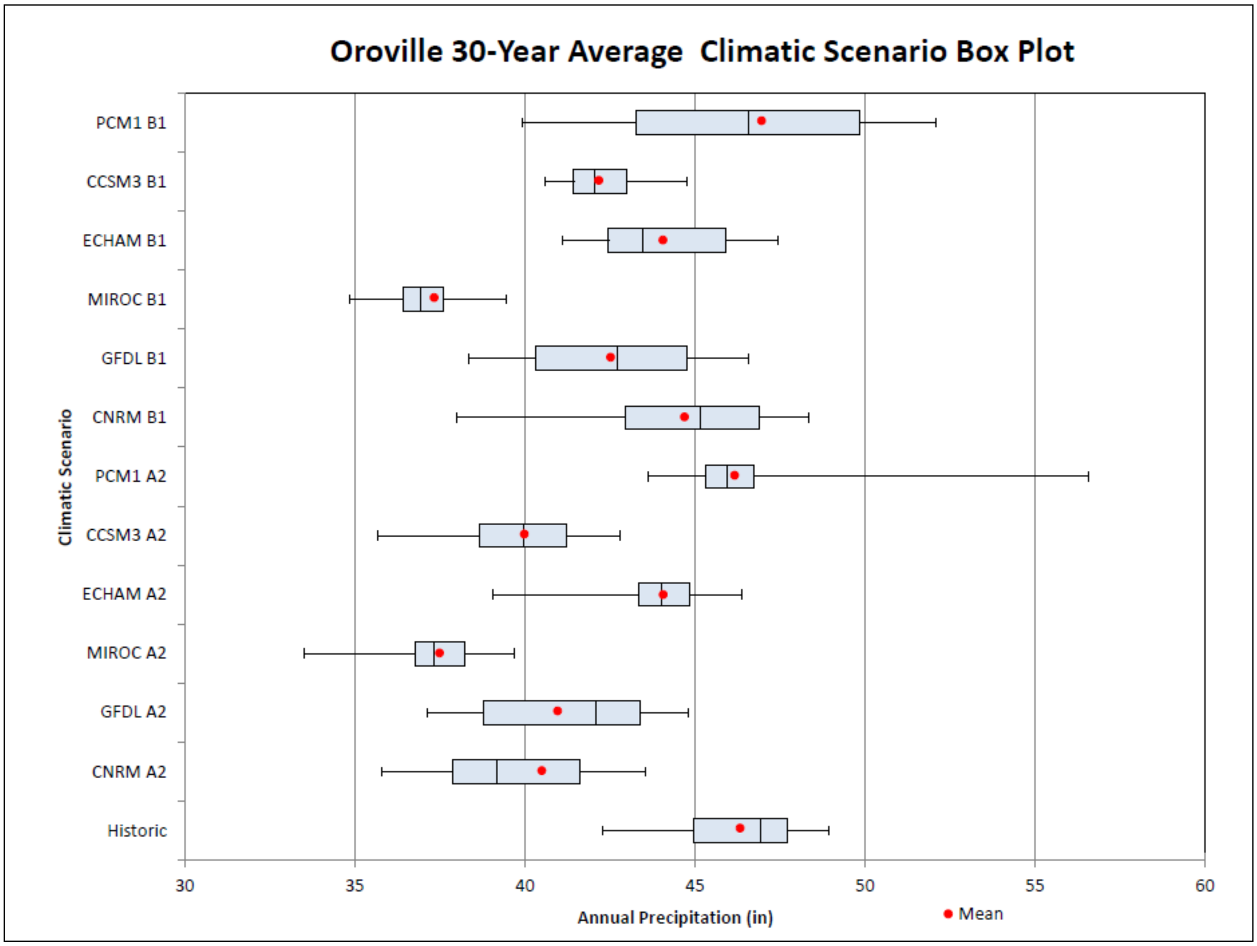


Figure 5-3 Variation in 30-Year Running Average Precipitation for Historical Record (1915-2003) and Alternative Scenarios of Future Simulated Climate (2011-2099) for Fresno

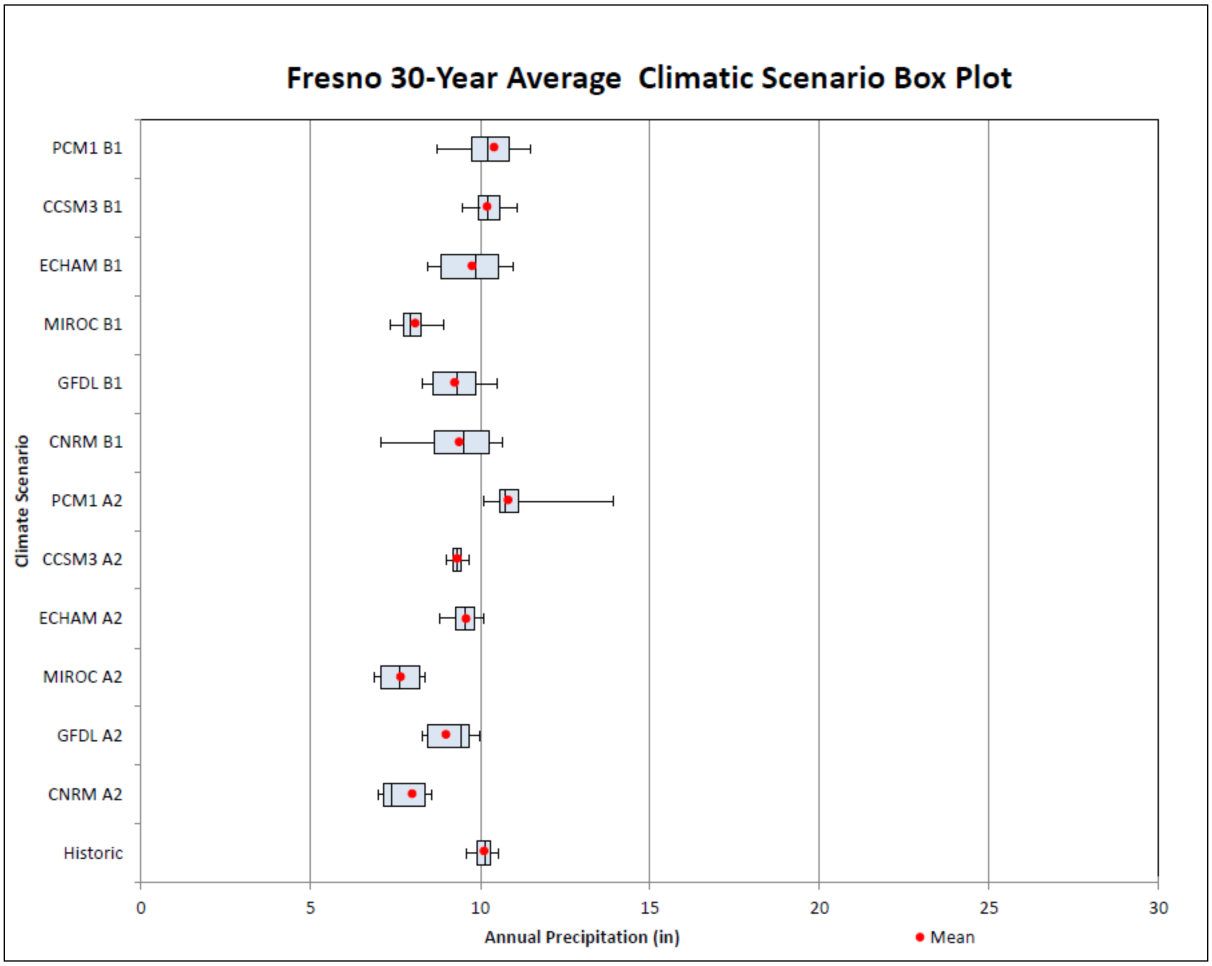


Figure 5-4 Variation in 30-Year Running Average Precipitation for Historical Record (1915-2003) and Alternative Scenarios of Future Simulated Climate (2011-2099) for Millerton

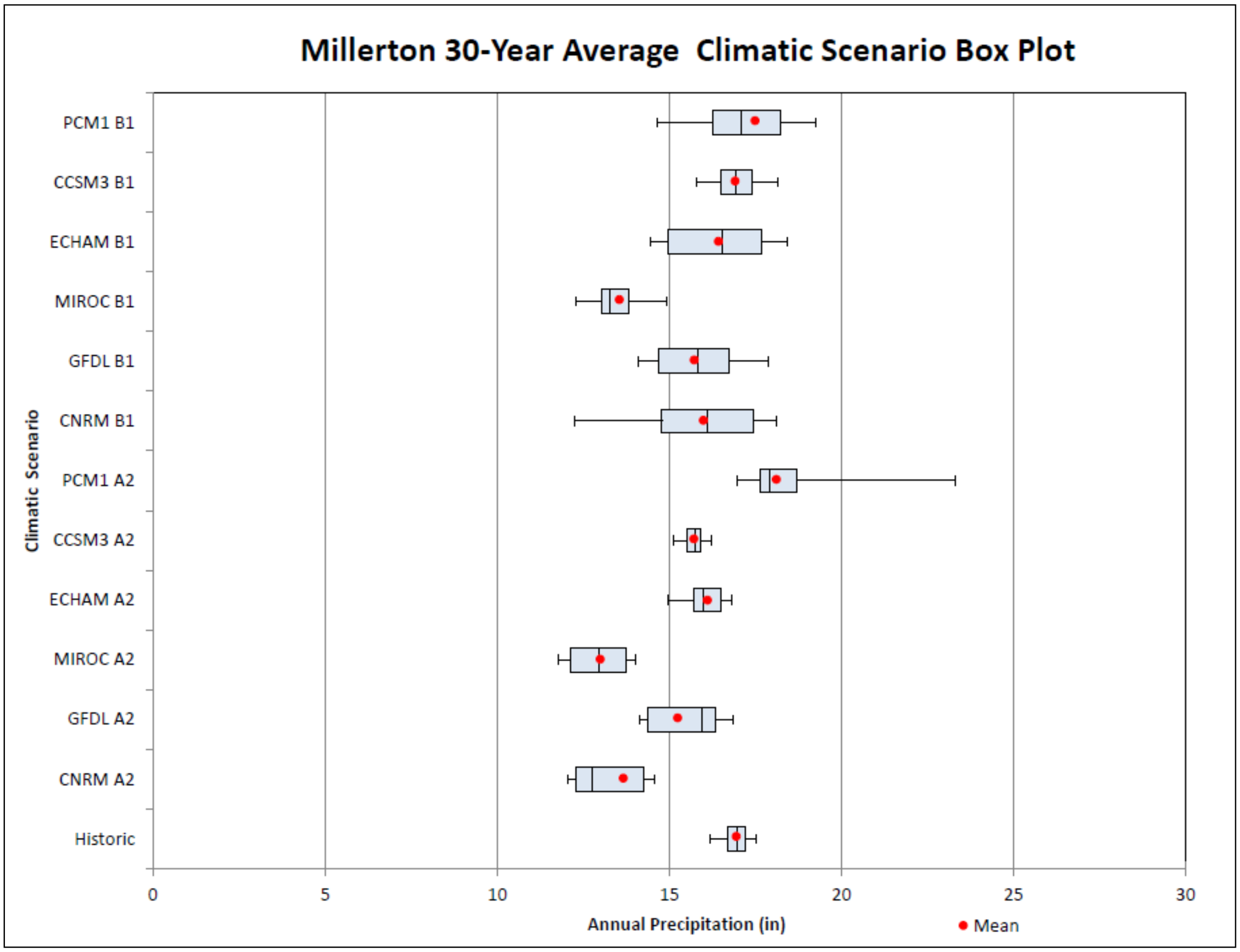
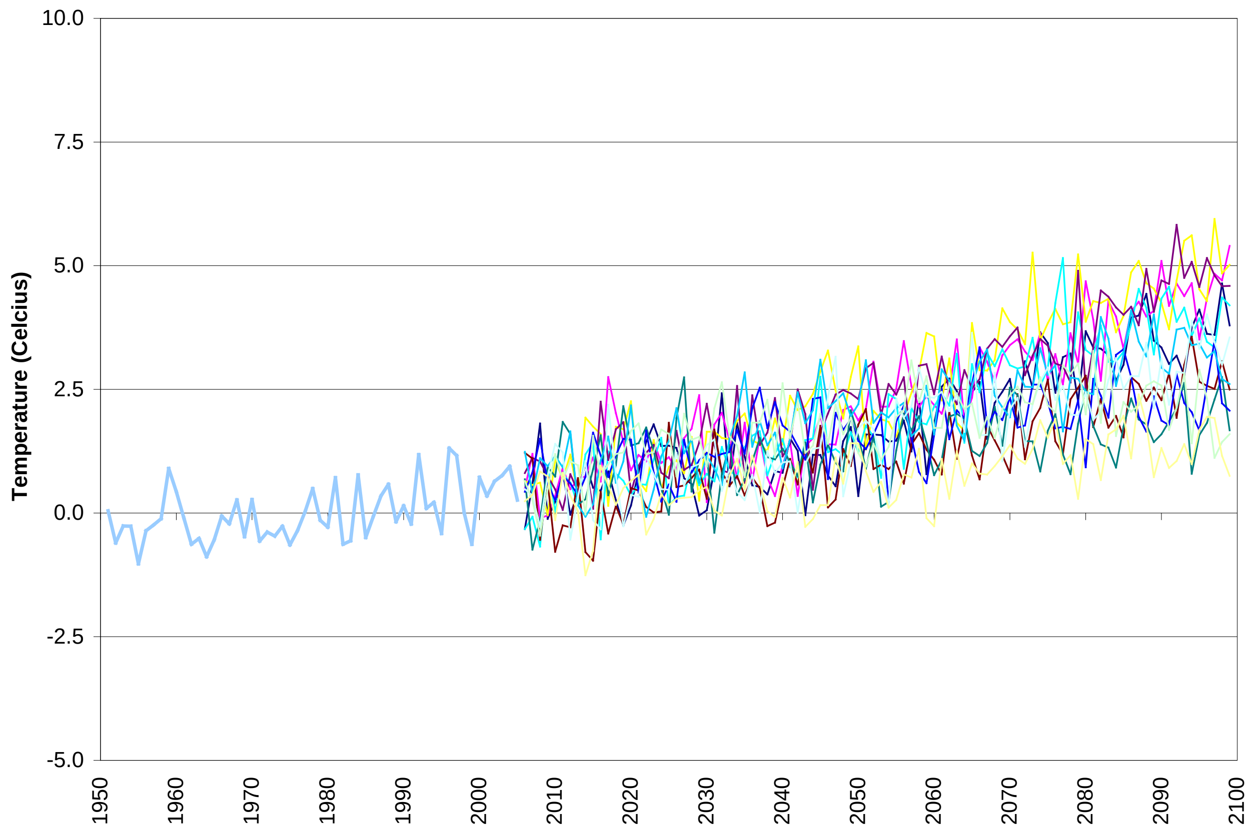


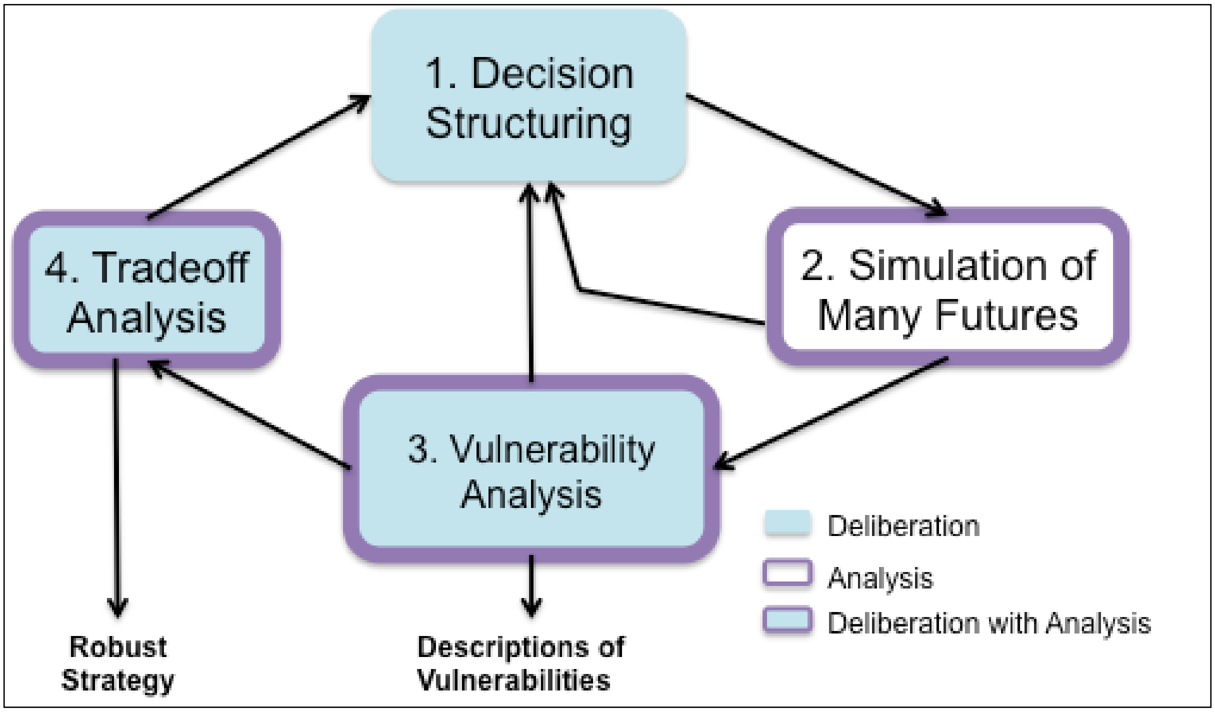
Figure 5-5 **Change in Average Annual Temperature from Historical 1951-2005 Average for Historical Period and 12 Scenarios of Future Climate Years 2006-2100 for Sacramento Valley Floor**



Note: In this figure, historical period shows actual demand (blue line). Each colored line represents 1 of 12 climate scenarios.

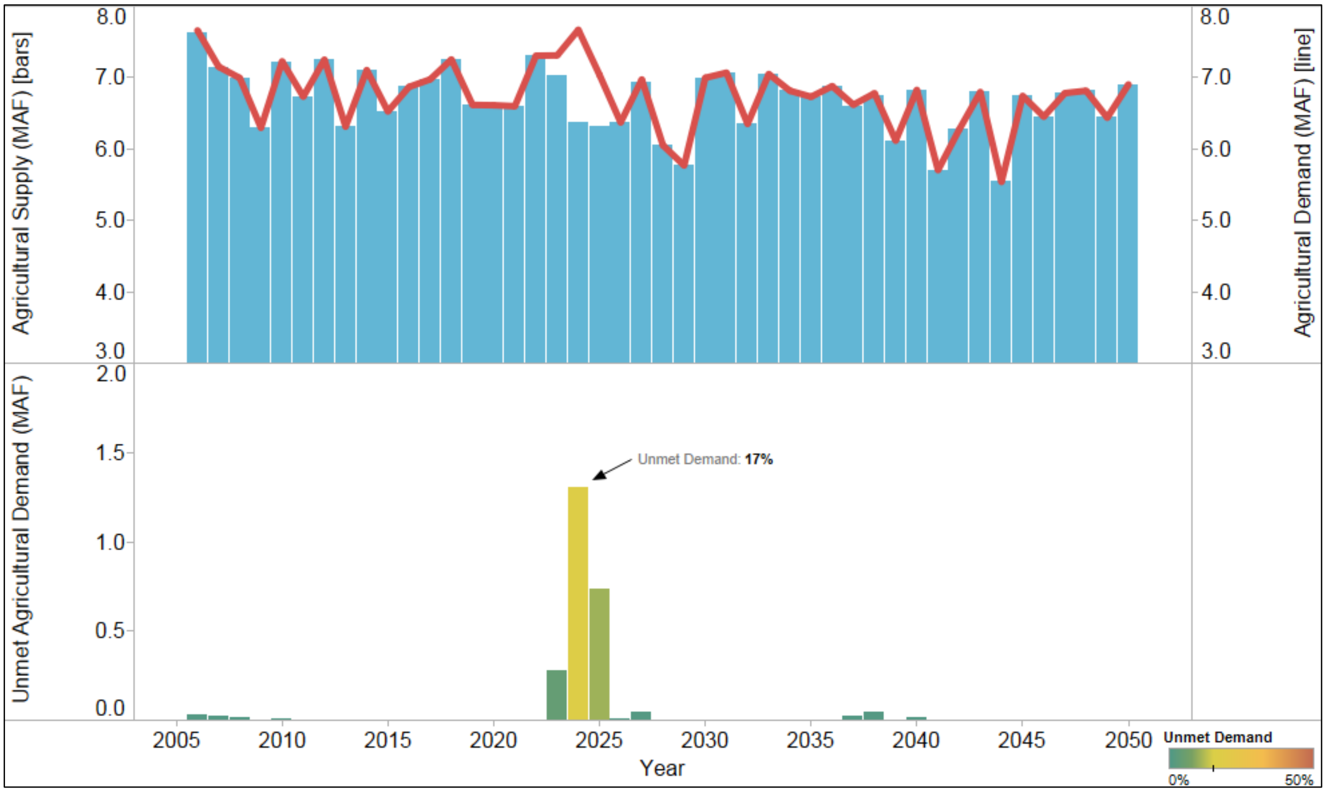
Figure 5-6 California Hydrological Regions Highlighting Three Central Valley Regions Used in Test Case

Figure 5-7 Robust Decision-Making Steps Used in Water Plan Analysis



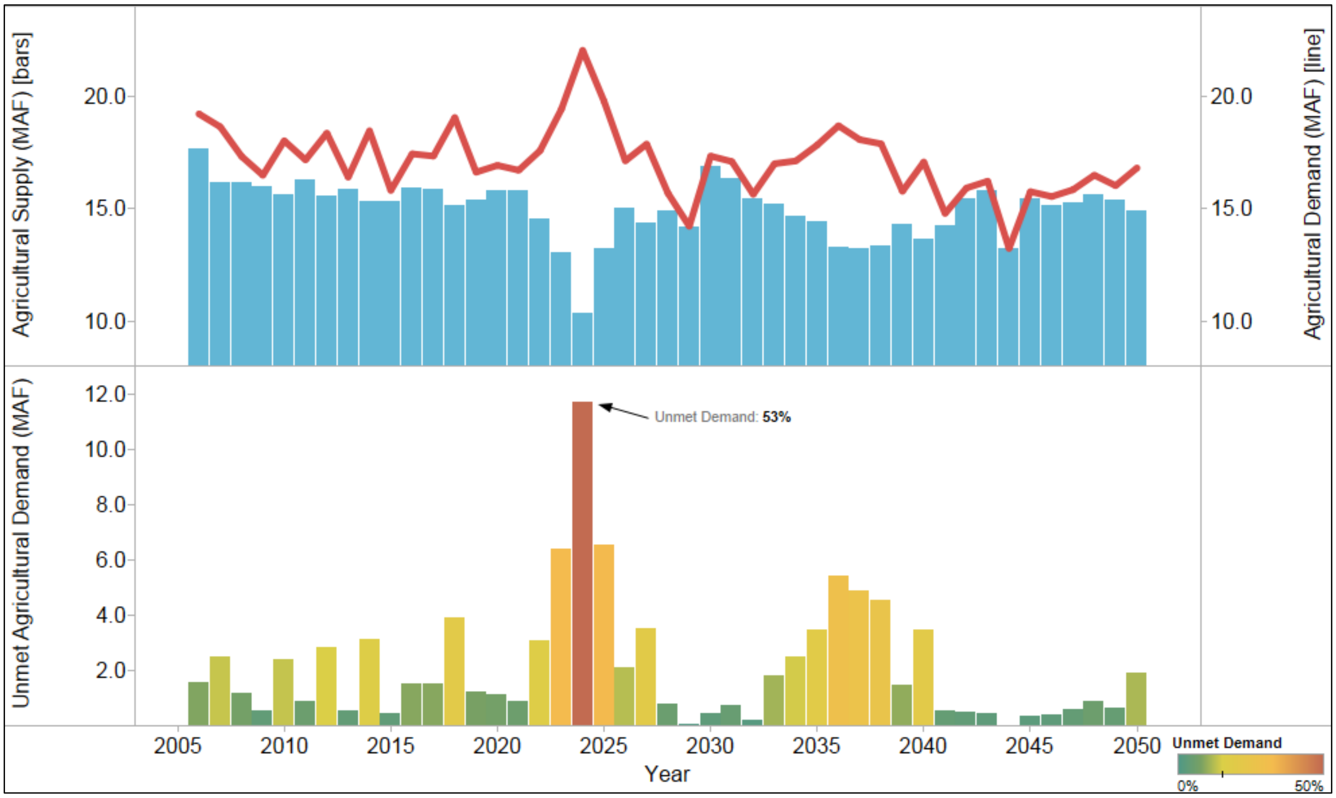
Source: Lempert et al. 2013

Figure 5-8 Single Simulation of Agricultural Supply, Demand, and Unmet Demand for the Sacramento River Hydrologic Region



MAF = million acre-feet

Figure 5-9 Single Simulation of Agricultural Supply, Demand, and Unmet Demand for the San Joaquin River and Tulare Lake Hydrologic Regions



MAF = million acre-feet

Figure 5-10 Range of Urban and Agricultural Reliability Results Across Futures

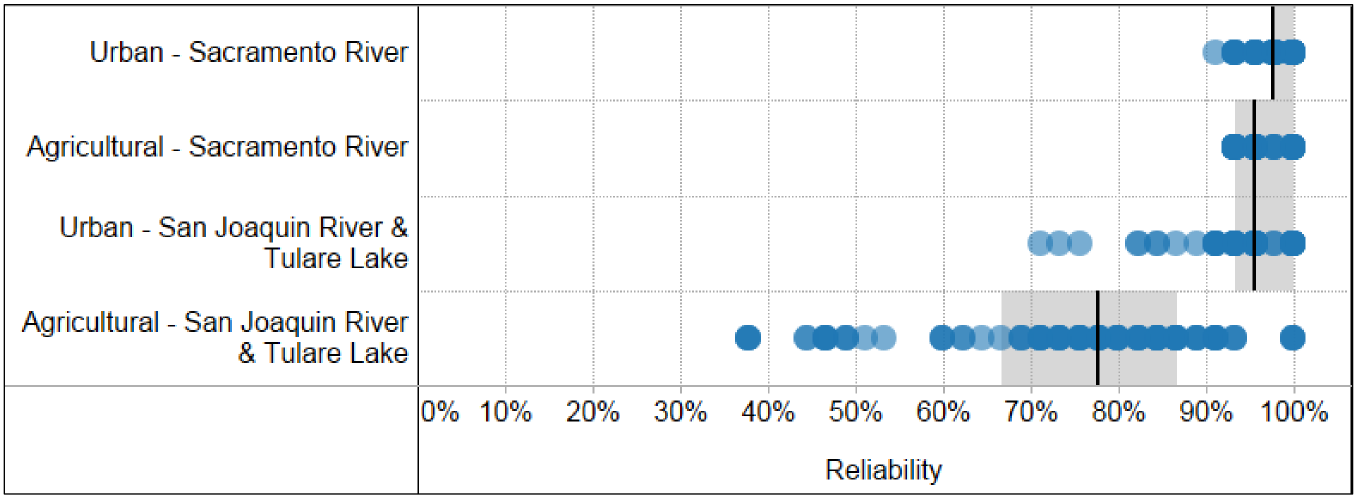


Figure 5-11 Range of Groundwater Storage Changes Across Futures

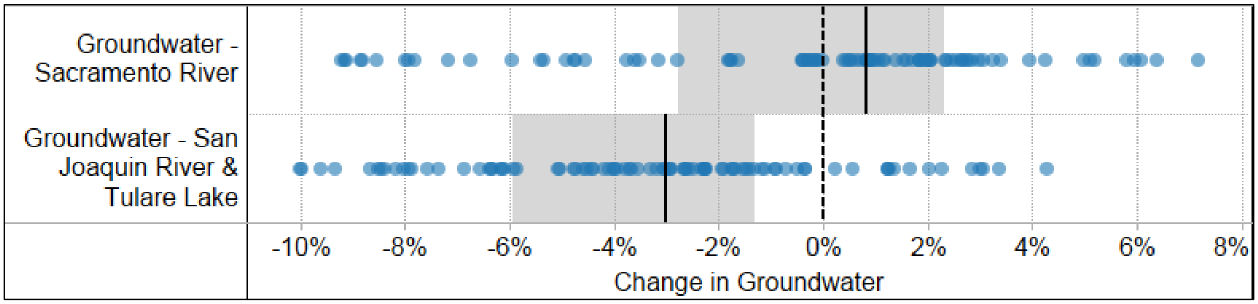
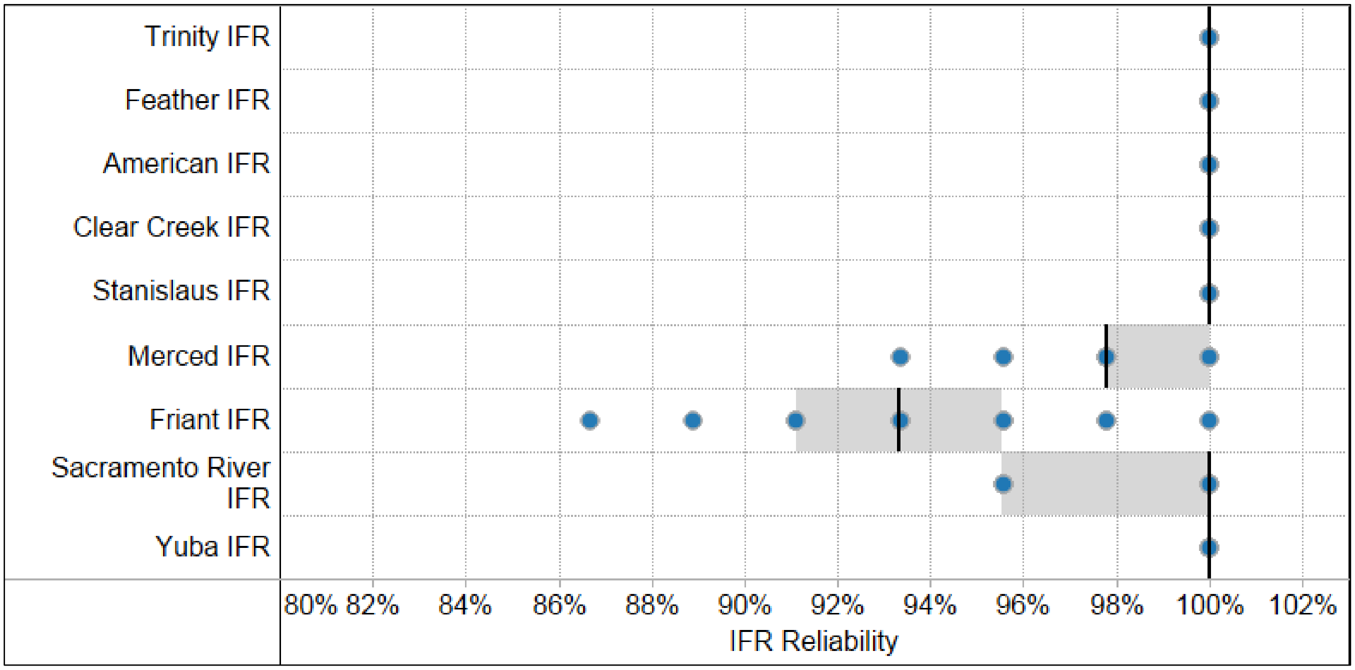


Figure 5-12 Range of Instream Flow Requirement Reliability Across Futures



IFR = Instream Flow Requirement

Figure 5-13 Climate Conditions Leading to Low Urban Reliability in the San Joaquin River and Tulare Lake Hydrologic Regions for the Low-Population and High-Density Land Use Scenario

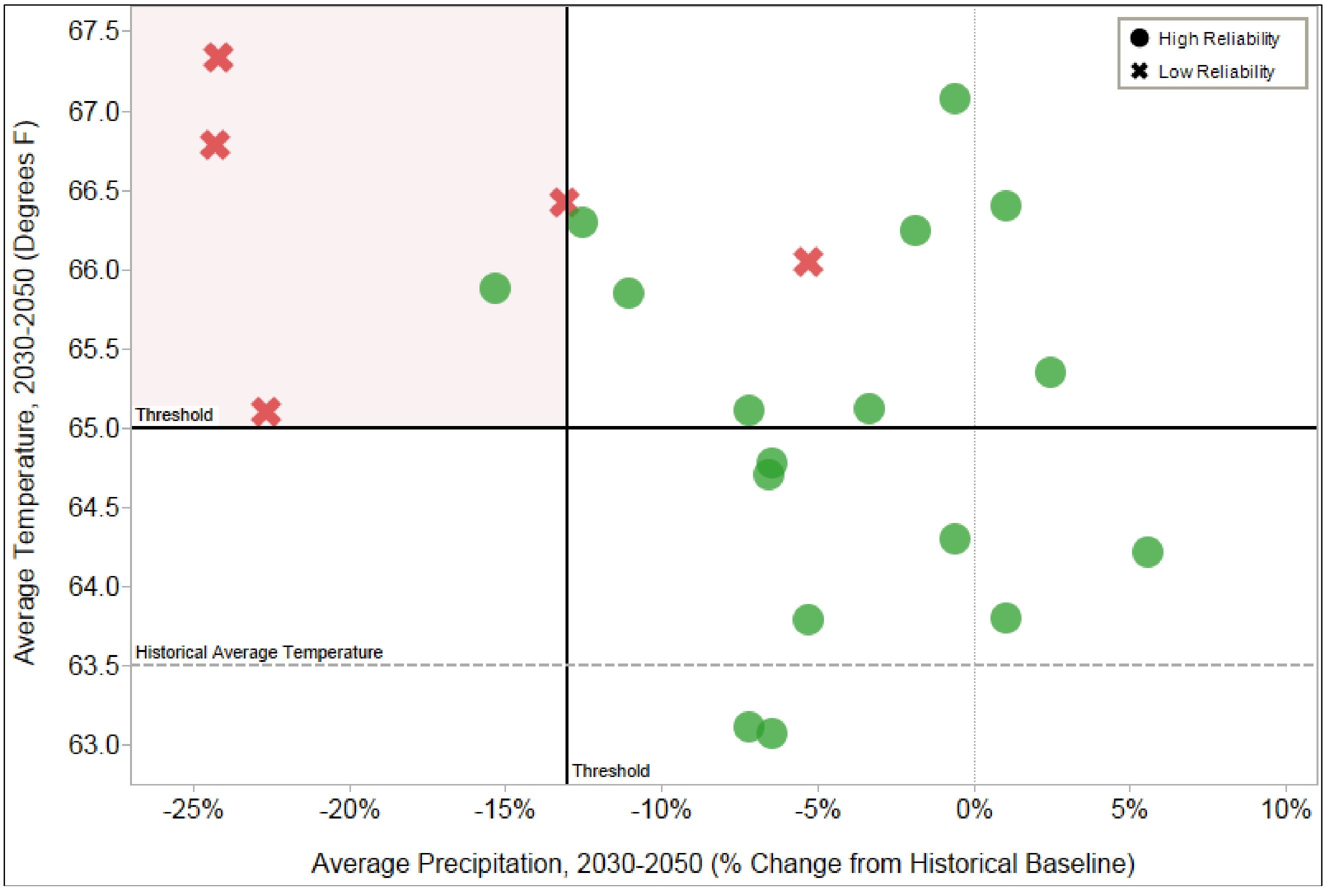


Figure 5-14 Climate Conditions in the San Joaquin River and Tulare Lake Hydrologic Regions Leading to Low Urban Water Reliability for the High-Population and Low-Density Land Use Scenario for Three Sets of Climate Scenarios

Figure 5-15 Climate Conditions Leading to Low Agricultural Reliability Results in the San Joaquin River and Tulare Lake Hydrologic Regions

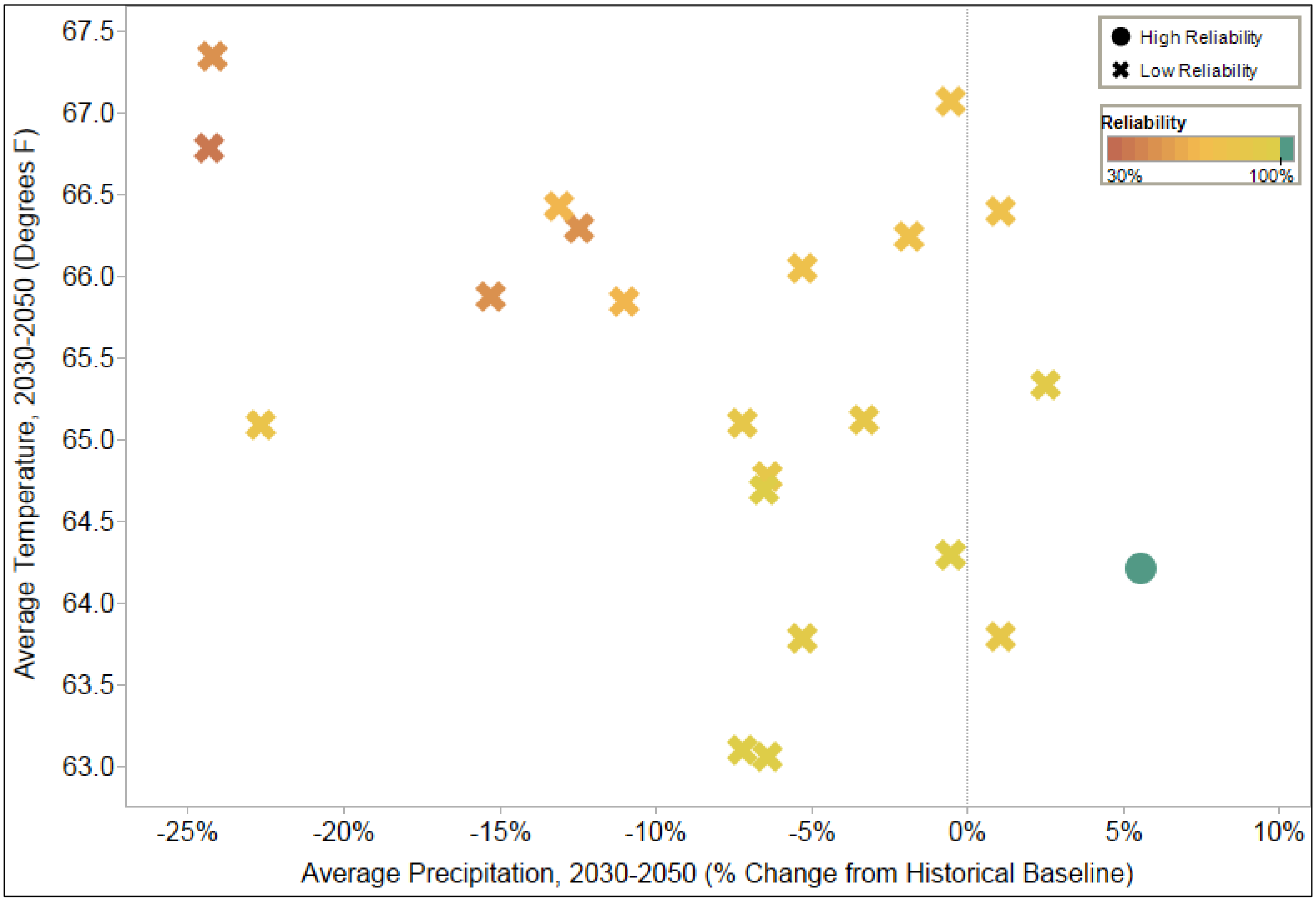


Figure 5-16 Tradeoff between Vulnerability Reduction and Cost of Example Response Packages from Proof-of-Concept Analysis

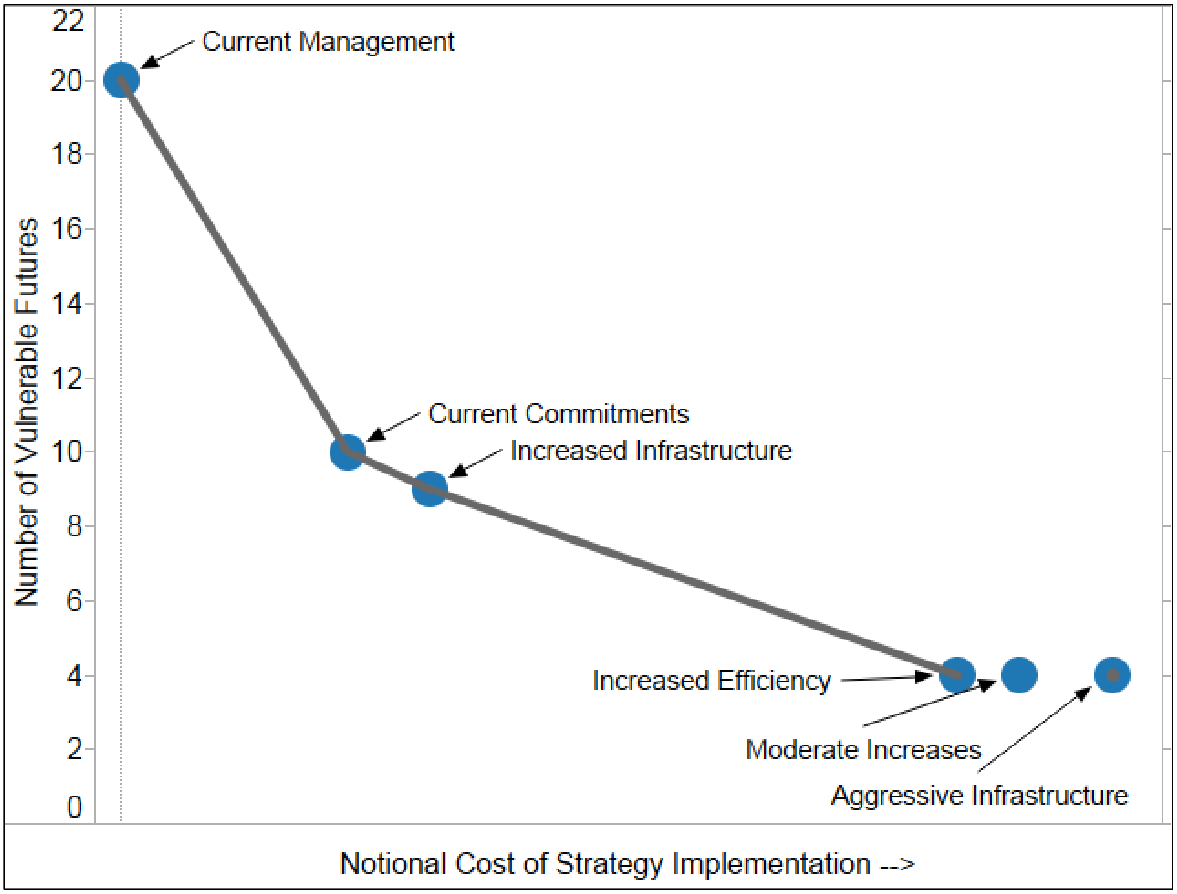


Figure 5-17 Change in Statewide Agricultural and Urban Water Demands for 117 Scenarios from 2006-2005 (million acre-feet per year)

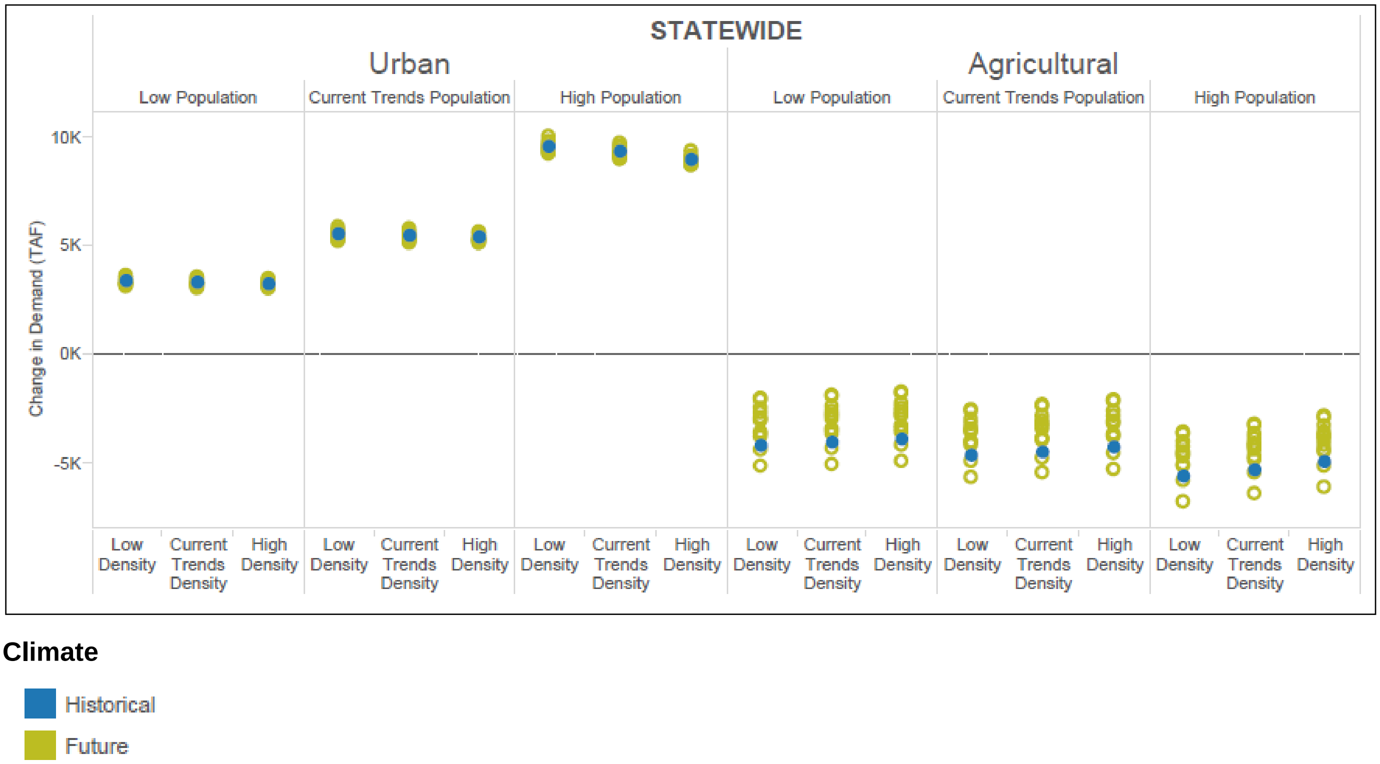


Figure 5-18 Change in Regional Agricultural and Urban Water Demands for 117 Scenarios from 2006-2005 (million acre-feet per year)

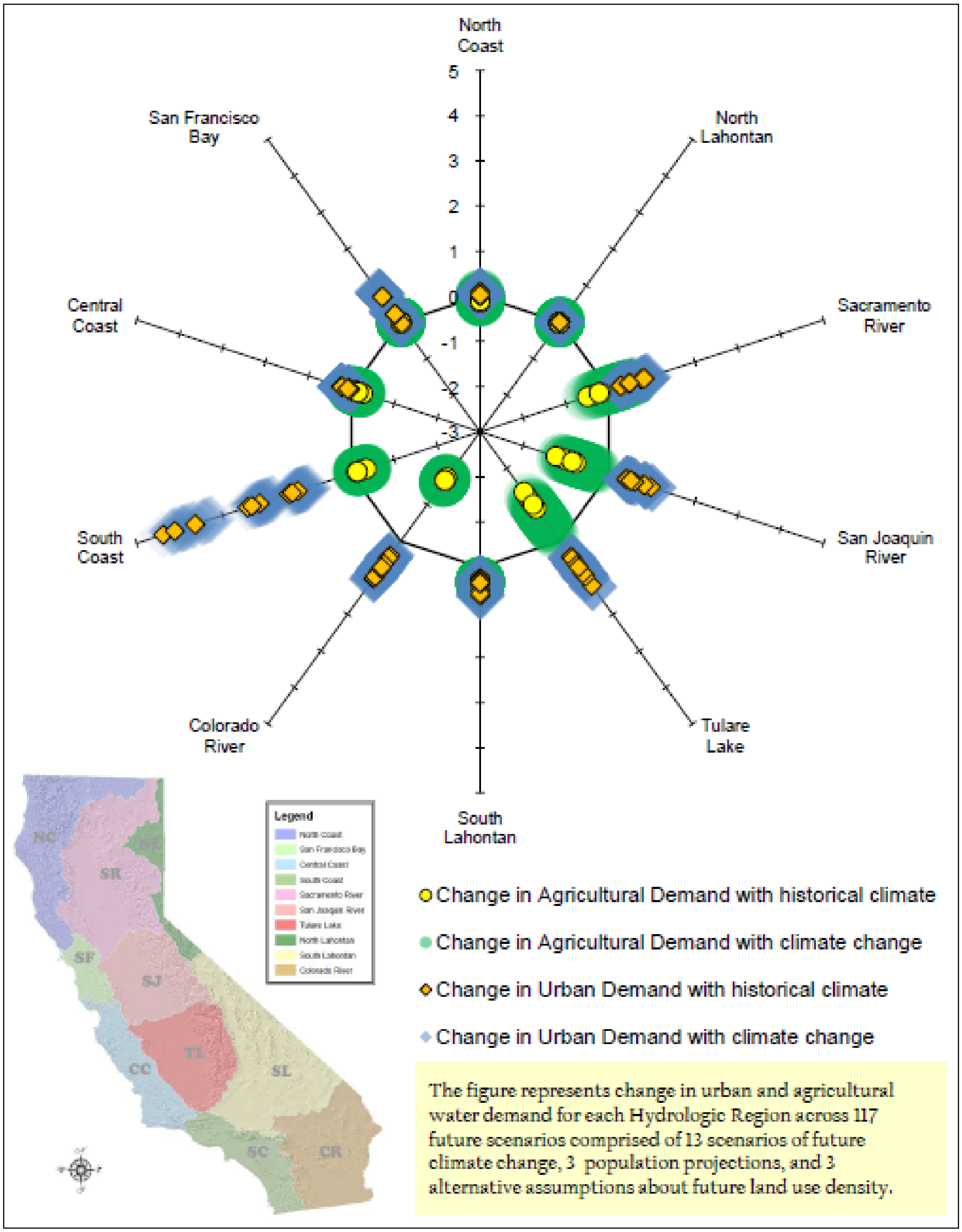


Figure 5-19 The California Water Sustainability Indicators Framework – Process

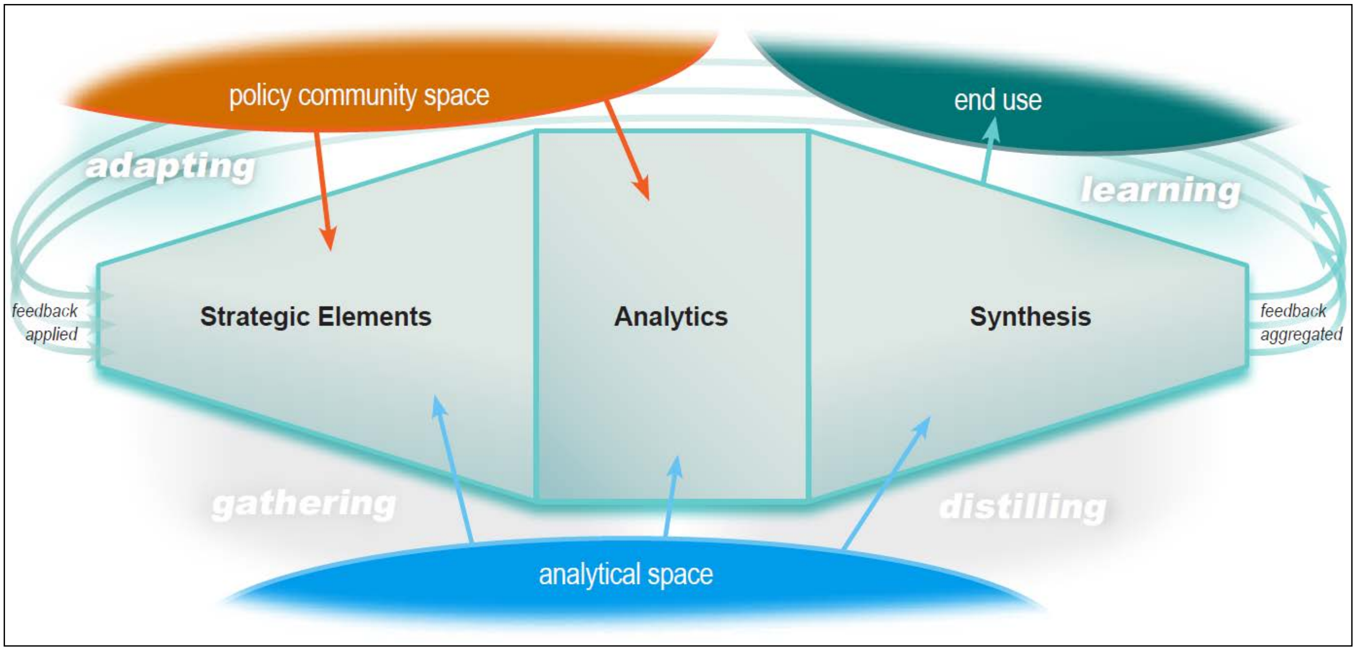
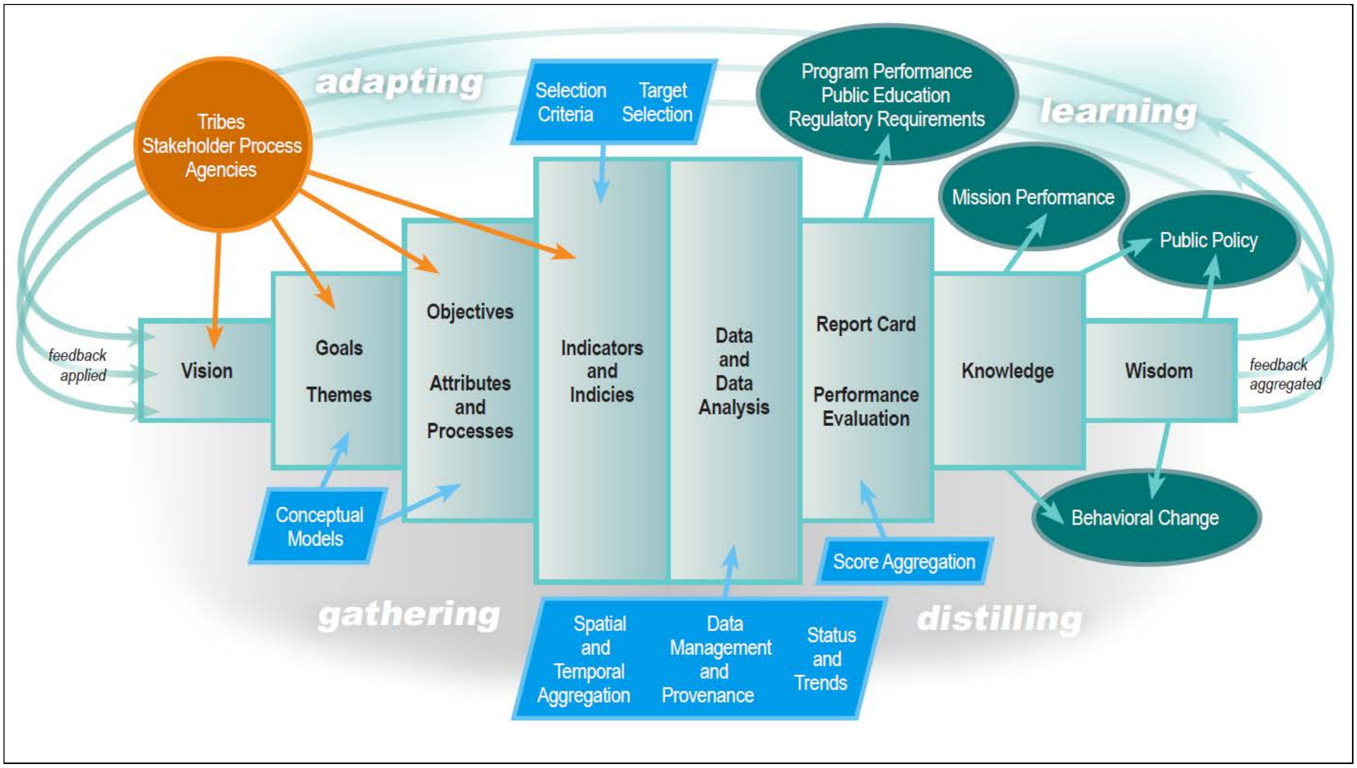


Figure 5-20 Details of the California Water Sustainability Indicators Framework



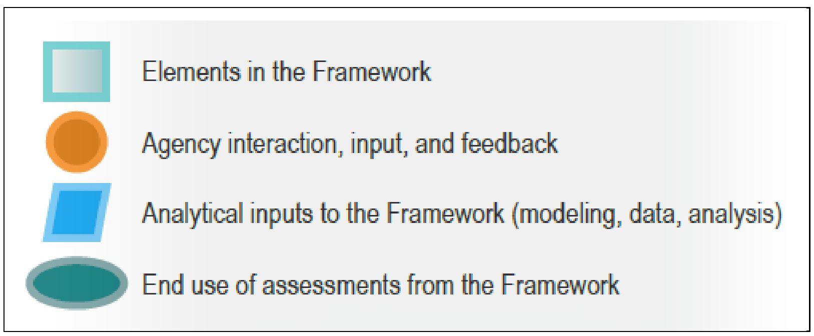


Figure 5-21 California's Blue and Green Water Footprint

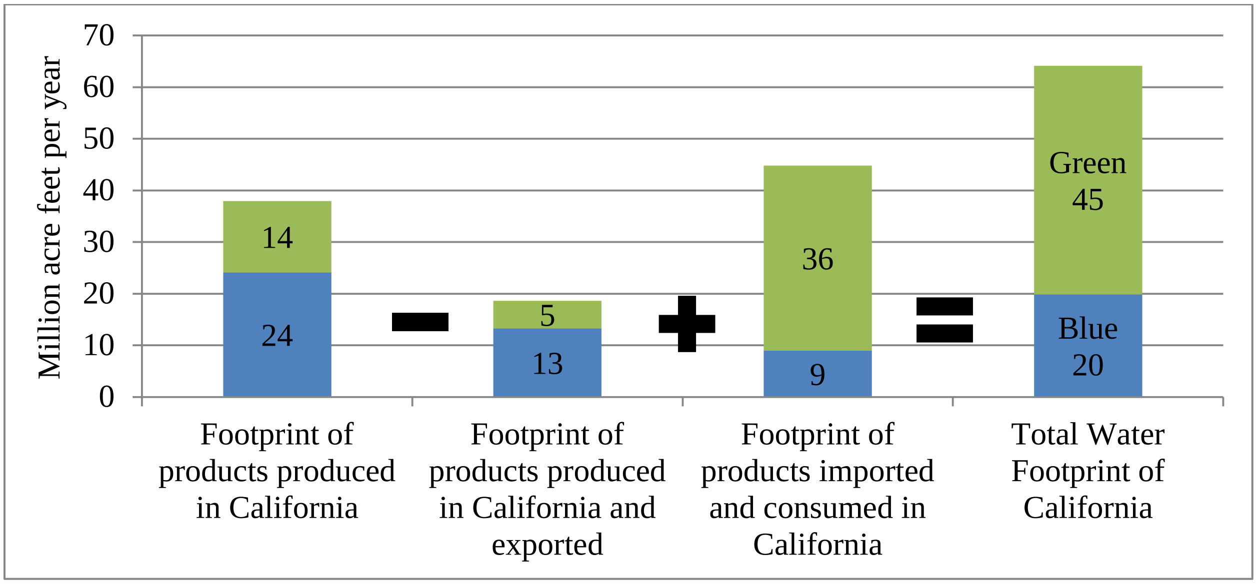


Figure 5-22 **Impervious Cover: Water Quality Index**

Figure 5-23 Impervious Cover: Geomorphic Processes

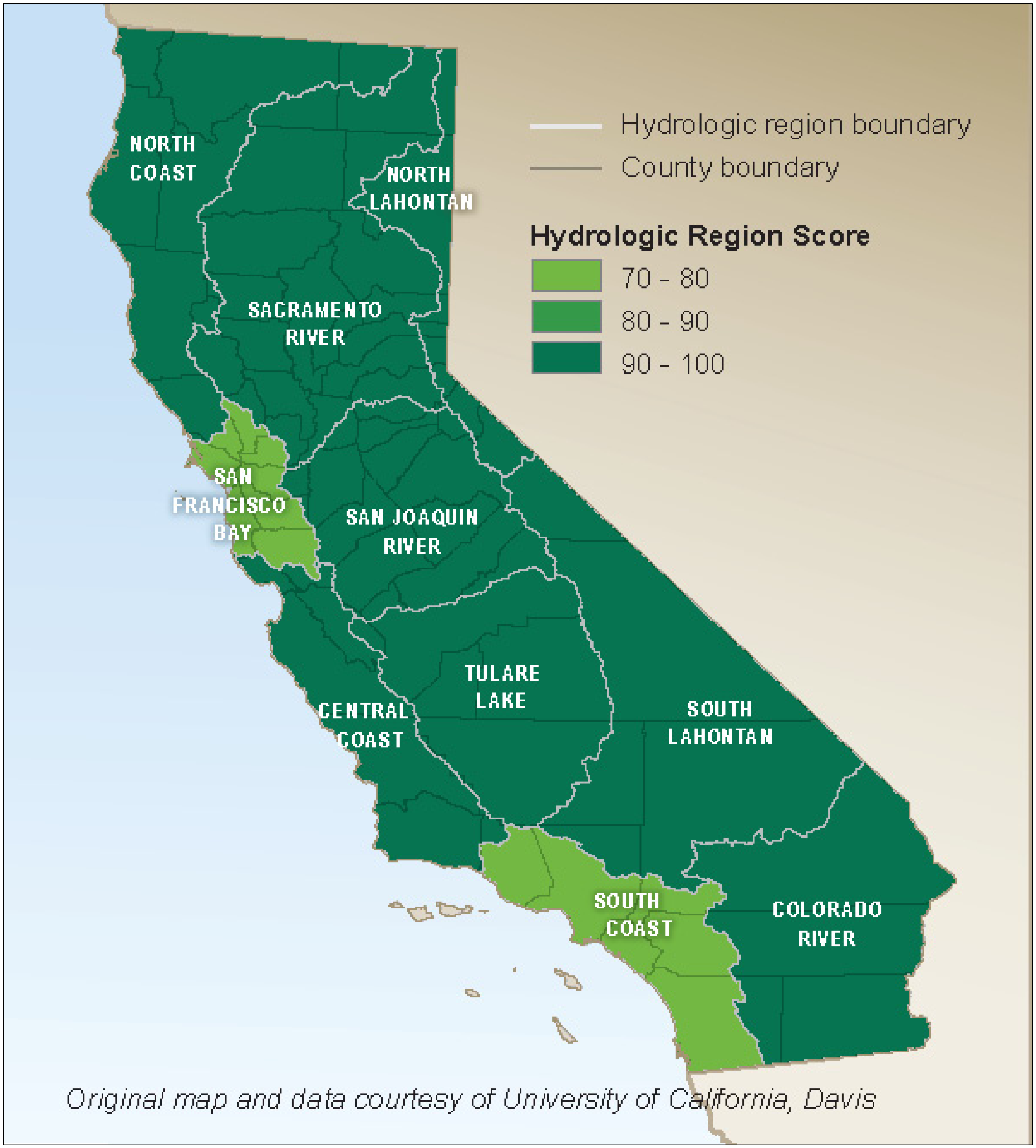


Figure 5-24 California Stream Condition Index

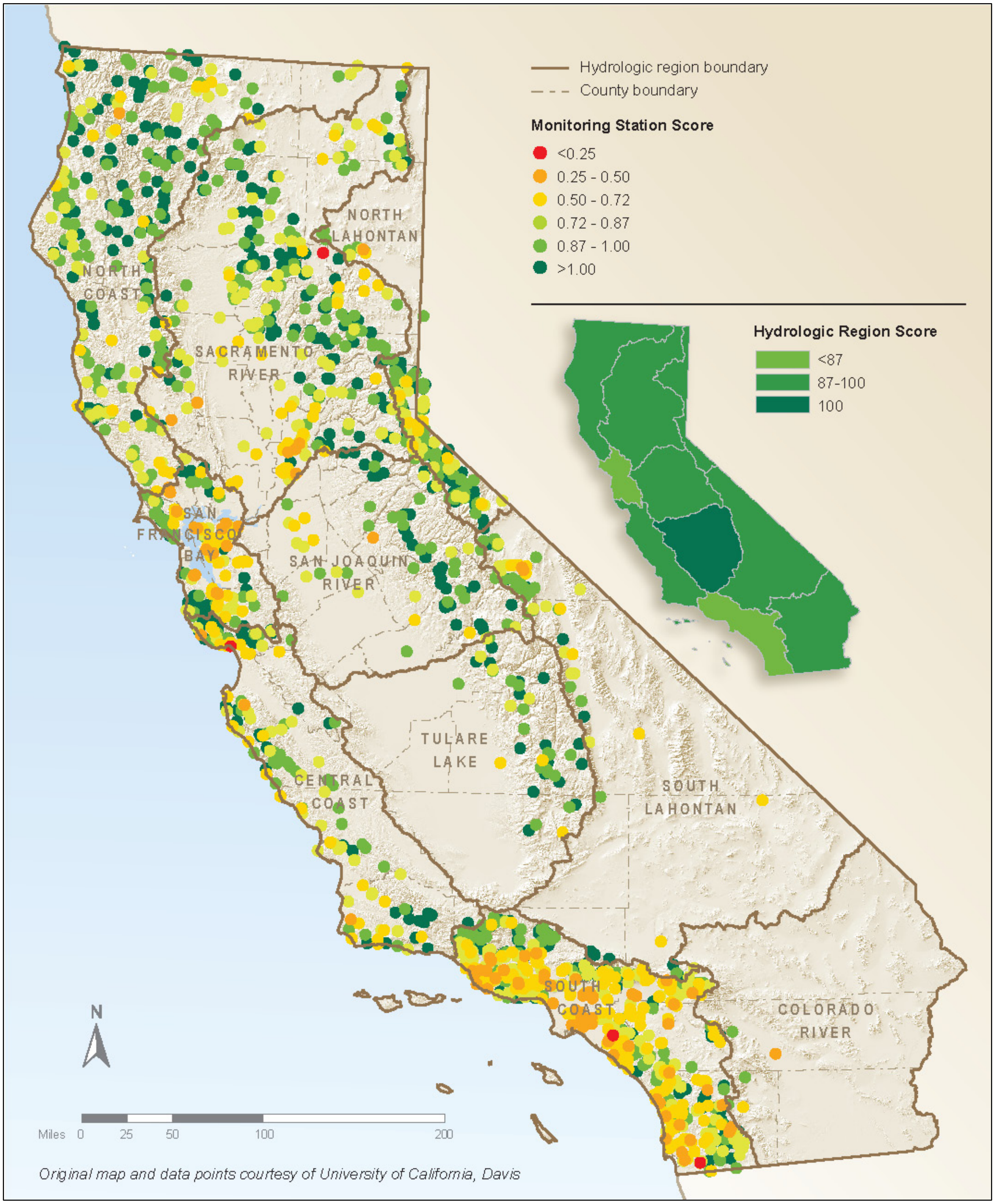
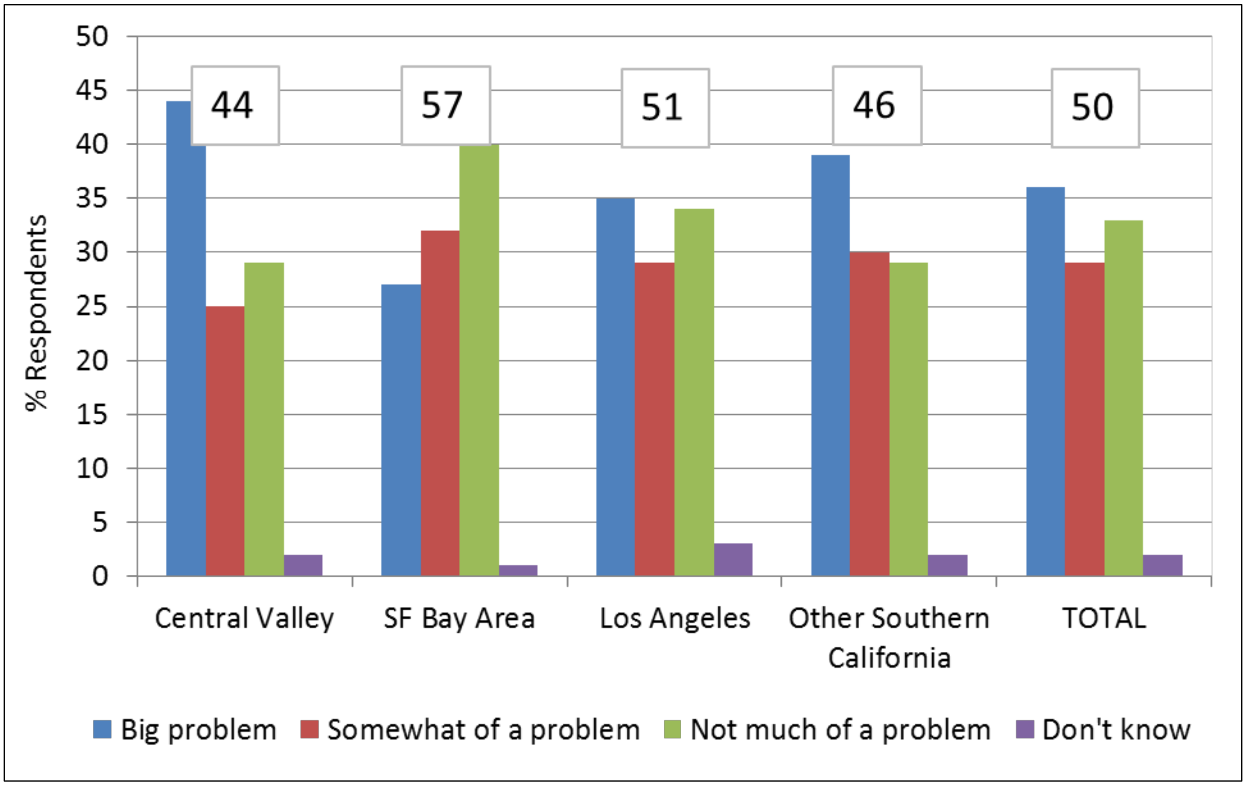


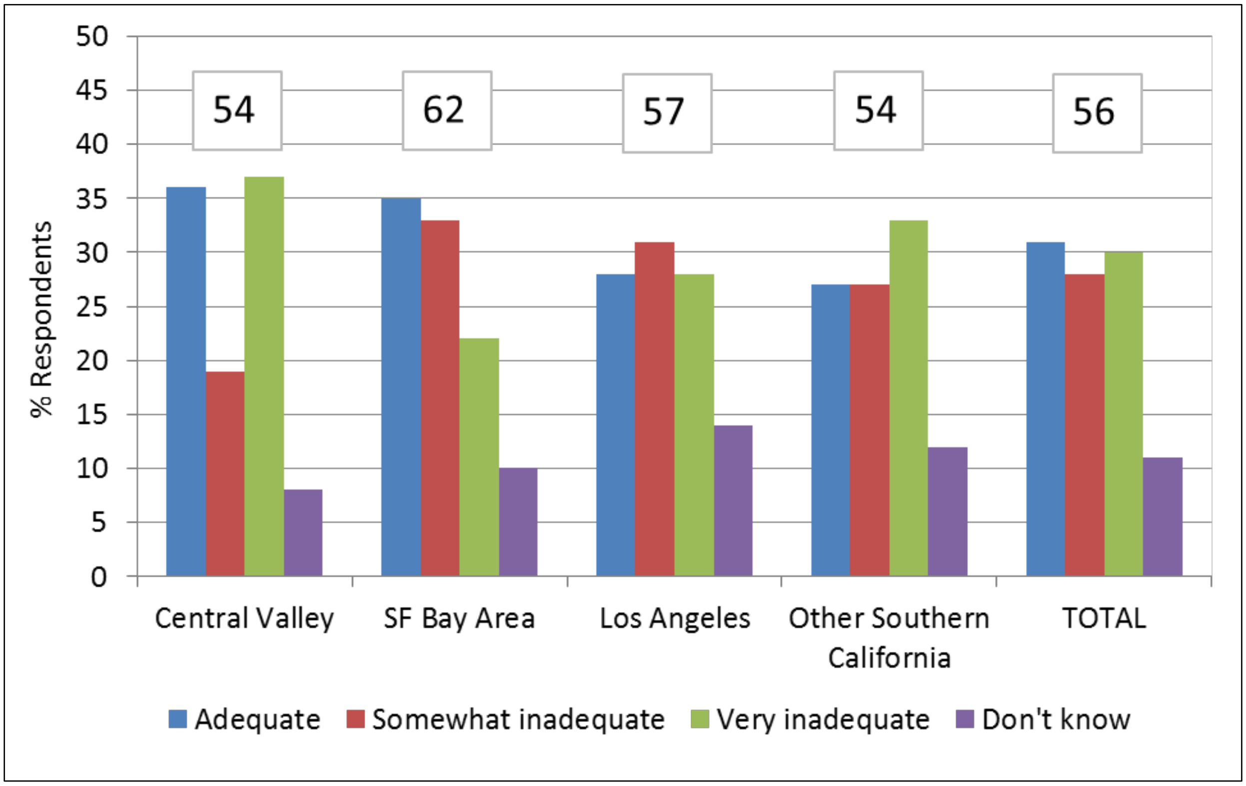
Figure 5-25 Fish Community Score for Hydrologic Regions

Figure 5-26 Public Perception by Region of Seriousness of Threats to the Public Water Supply



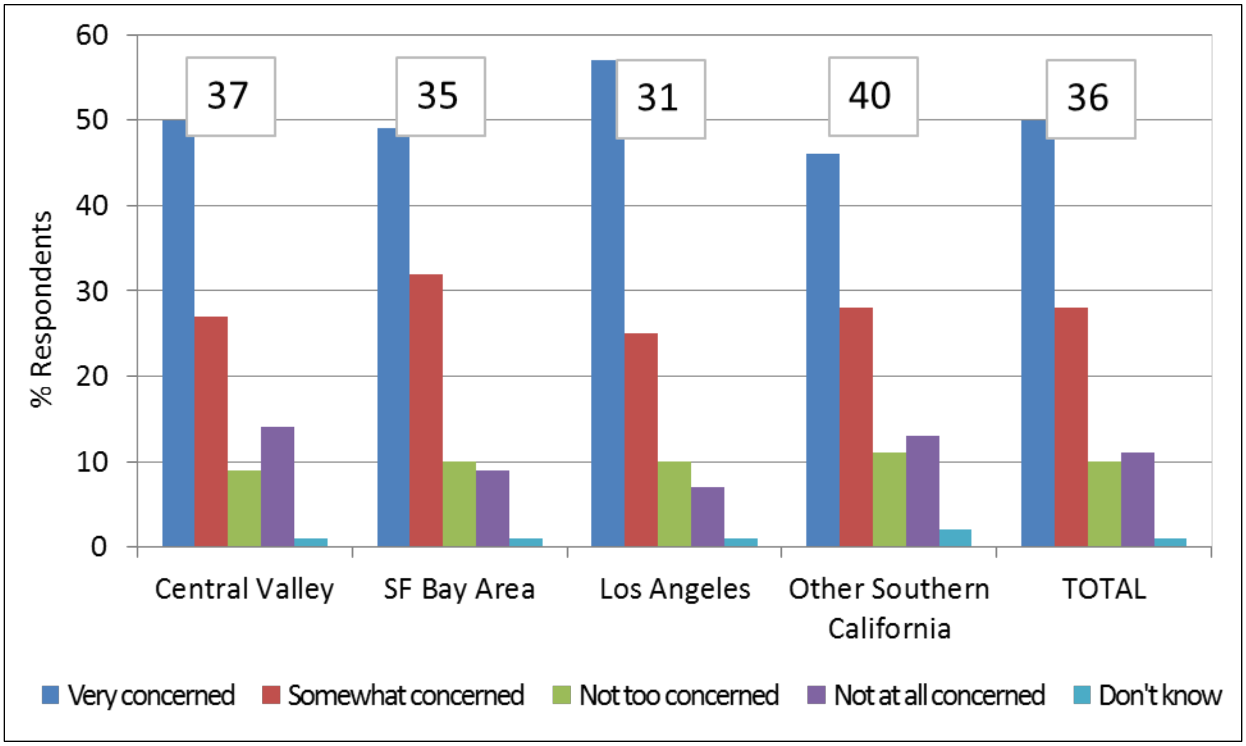
Notes: December 2012, sample = 7,315 respondents. Scores are shown in boxes above each regional summary.

Figure 5-27 Public Perception of Security of Future Water Supplies



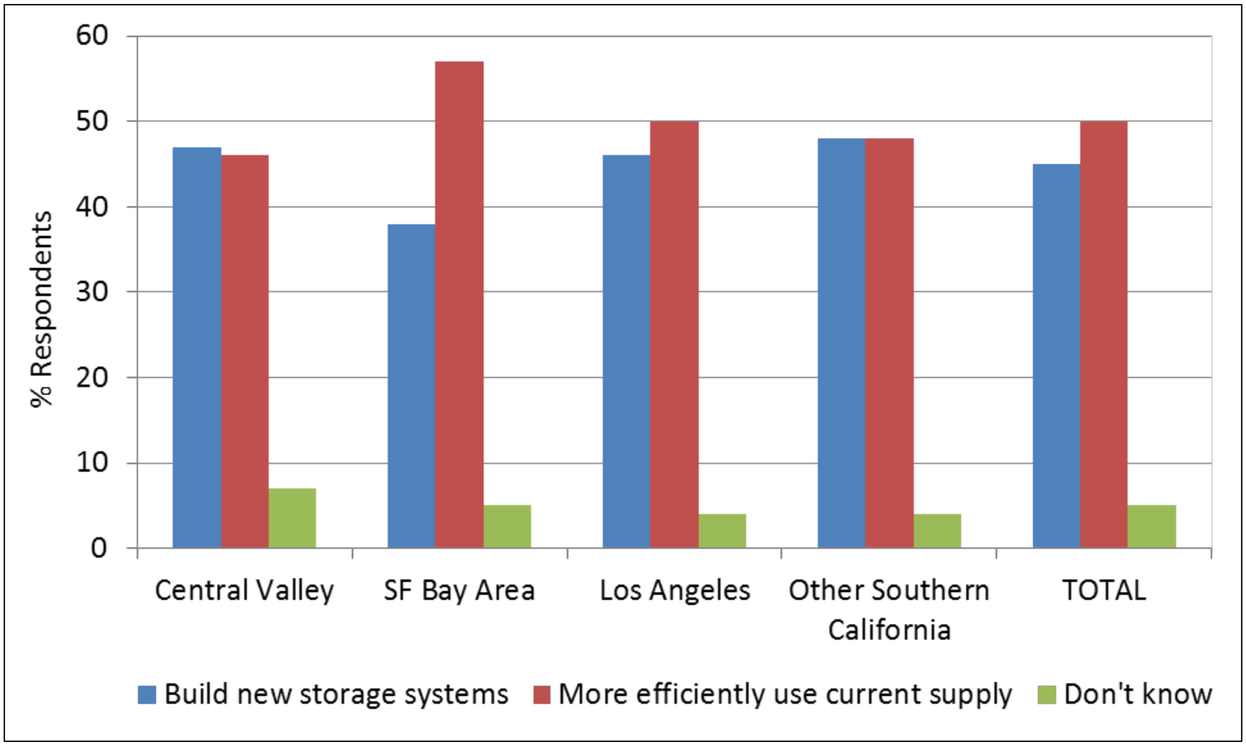
Notes: December 2009, sample = 1,825 respondents. Scores are shown in boxes above each regional summary.

Figure 5-28 Public Perception of Effects of Climate Change on Future Water Supplies



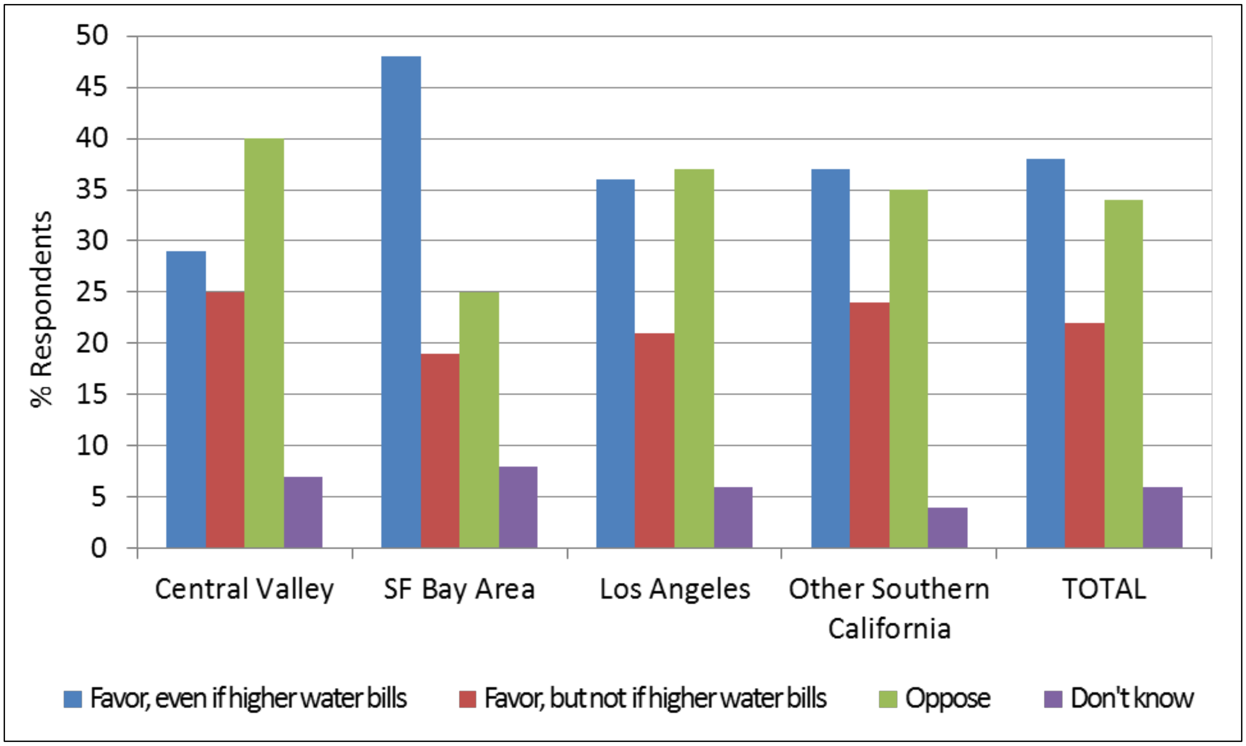
Notes: July 2011, sample = 4,580 respondents. Scores are shown in boxes above each regional summary.

Figure 5-29 Public Perception of Future Water Management Strategies to Maintain Water Supply



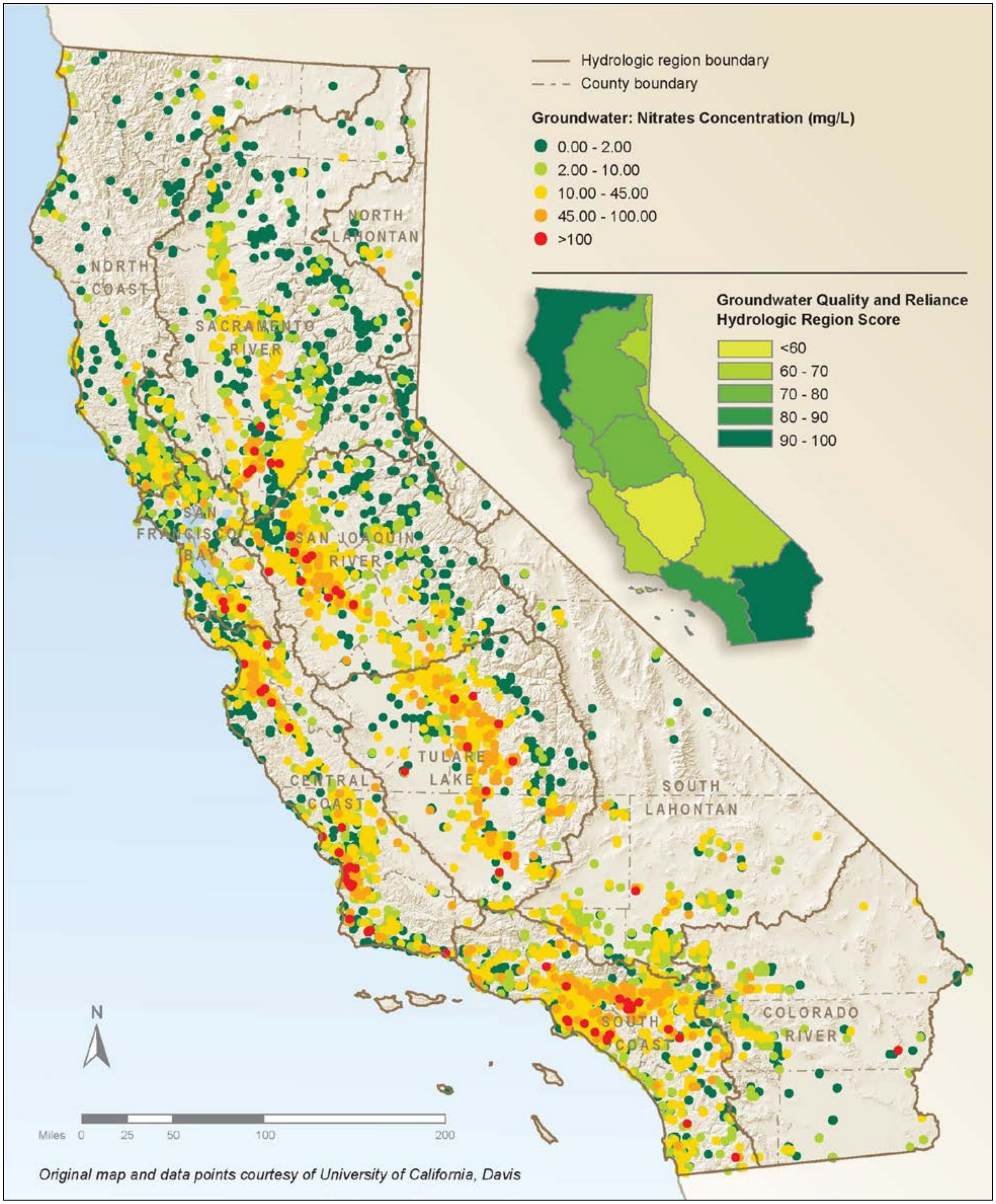
Notes: December 2012, sample = 3,904 respondents.

Figure 5-30 Public Favor for Improving Conditions for Fish, Including Payment Strategies



Notes: December 2012, sample = 1,833 respondents.

Figure 5-31 Groundwater and Drinking Water Contamination Score for Hydrologic Regions



Original map and data points courtesy of University of California, Davis

Box 5-1 Uncertainty, Risk, and Sustainability

Uncertainty. Uncertainty is what we do not know about the system. For example, engineers do not know the foundation conditions under all California levees. Uncertainty can be reduced by reducing data gaps to increase knowledge.

Risk. Most risks originate from such hazards as floods, earthquakes, and droughts that would occur even if all uncertainty could be eliminated. Reducing uncertainty provides a clearer view of what the risks to the system are.

> *Risk* is the probability of the occurrence (multiplied by) consequences of the occurrence over a range of potential events.

Sustainability. A sustainable system or process has longevity and resilience. A sustainable system manages risk but cannot eliminate it. A sustainable system generally provides for the economy, the ecosystem, and social equity. Water sustainability is the dynamic state of water use and supply that meets today's needs without compromising the long-term capacity of the natural and human aspects of the water system to meet the needs of future generations. For example, planning ways to eventually eliminate drafting more groundwater than can be recharged over the long term is one approach for improving sustainability.

Box 5-2 Sources of Future Change and Uncertainty

Sources of Gradual or Long-term Change and Uncertainty

Urban Land Use (population). Projecting future changes in population, development patterns, changes in runoff and infiltration with increased impervious area, and changes in water quality impacts becomes more uncertain with the time frame of the projection.

Agricultural Land Use. Agricultural water use is influenced by land conversions to urban or ecosystem uses, but also depends on cropping patterns driven by water availability and the world economy.

Other Land Use. Conversions of land to ecosystem or other uses can change water use, water quality, ecosystem health, and many other factors. Some ecosystem uses consume more water per acre than agricultural and urban uses.

Climate Change. The changing climate presents many uncertainties in the magnitude, pattern, and the rate of potential change:

- **Snowpack.** California's snowpack, a major part of annual water storage, is decreasing with increasing winter temperatures.
- **Hydrologic Pattern.** Warmer temperatures and decreasing snowpack cause more winter runoff and less spring/summer runoff.
- **Rainfall Intensity.** Regional precipitation changes remain difficult to determine, but larger precipitation events could be expected with warmer temperatures in some regions.
- **Sea Level Rise.** Sea level rise is increasing the threat of coastal flooding, salt water intrusion, and even disruption of water exports from the Sacramento-San Joaquin Delta (Delta) should levees fail on key islands and tracts.
- **Water Demand.** Plant evapotranspiration increases with increased temperature.
- **Aquatic Life.** Higher water temperatures are expected to have a negative effect on some species and may benefit species that compete with native species.
- **Greenhouse Gas Emissions — Carbon Intensity or Carbon Footprint.** Storage, transport, and treatment of water involves the use of substantial amounts of energy, which in most cases result in the release of greenhouse gas emissions that contribute to climate change. Each water management strategy should be evaluated for its contribution to the accumulation of greenhouse gasses in our atmosphere.

Sources of Sudden or Short-term Change and Uncertainty

Delta Vulnerabilities. The Delta is highly susceptible to flooding and to disruption of significant water supply to many areas of the state.

Droughts. The severity, timing, and frequency of future droughts are uncertain.

Floods. The severity, timing, and frequency of future floods are uncertain.

Earthquakes. Even though more is now known about earthquakes, their location, timing, and magnitudes can have various effects on water systems.

Facility Malfunction. Deferred maintenance and aging infrastructure can cause unexpected outages in portions of the system.

Chemical Spills. Chemical spills are unpredictable, but can cause disruption of surface water and groundwater supplies.

Intentional Disruption. Vandalism, terrorist acts, and even cyber threats can have serious potential impacts on the operational capability of water delivery and treatment systems.

Fire. Wildfire in local watersheds can change runoff characteristics and affect water quality for decades.

Economic disruption. Sudden changes in the economy influence the ability to pay for improvements to the water management system.

Changing Policies/Regulations/Laws/Social Attitudes. Some changes in policies, regulations, laws, and social attitudes may be gradual, but some may be sudden:

- **Endangered species.** New listings of endangered species can require significant changes to the operation of the water system and the distribution of water supplies among agricultural, urban, and environmental uses.
- **Plumbing Codes.** Future changes in plumbing codes, such as the one for installing ultralow-flow toilets, could allow use of innovative water fixtures to conserve water.
- **Emerging Contaminants.** The nature and impact of contaminants may be changing in the future, especially as new health and ecological risk information is obtained.

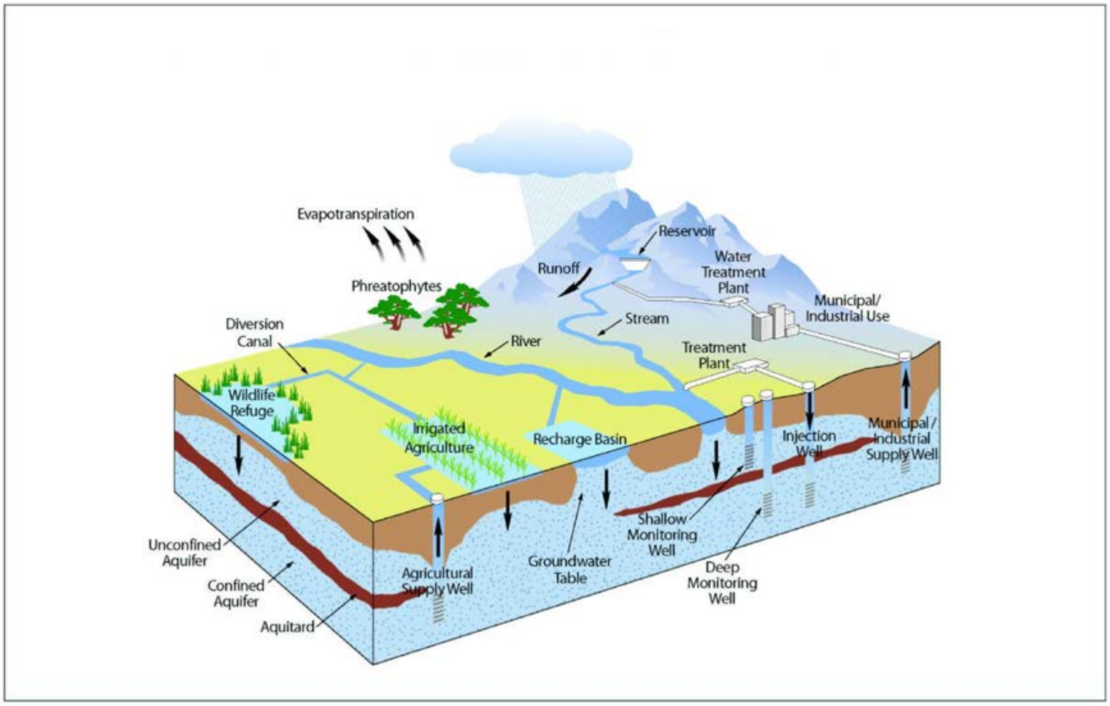
Box 5-3 Managing Floods versus Managing Flood Risk

Managing floods means building and operating facilities, such as dams, weirs, levees, and pump stations, to safely store and convey flood flows within designated channels to reduce the chance of flooding. Although such improvements can greatly reduce flood risk, they cannot entirely eliminate it. Subsequently, floodplains are often developed because of the perception that the chance of flooding has been eliminated. As a result, the overall flood risk (paradoxically) can increase following construction of flood control facilities. Flood risk is the combined effect of the chance of flooding and the property that would be damaged if flooded. Managing flood risk means either reducing the chance of flooding or the population and property exposed to flooding, or a combination of both. Thus, managing flood risk can include flood control facilities, as well as limiting floodplain development; elevating structures above flood elevations; creating natural flood storage and groundwater recharge areas; and using flood risk notification, flood insurance, and flood preparedness.

Source: California Department of Water Resources 2012

Box 5-4 Central Valley WEAP Model

The California Water Plan supported the development of a model of the Central Valley by using the Water Evaluation and Planning (WEAP) system (see www.weap21.org). The WEAP system is a comprehensive, fully integrated river basin analysis tool. It is a simulation model that includes a robust and flexible representation of water demands from different sectors and the ability to program operating rules for infrastructure elements, such as reservoirs, canals, and hydropower projects (Purkey and Huber-Lee 2006; Purkey et al. 2007; Yates, Purkey et al. 2005; Yates, Sieber et al. 2005; Yates et al. 2008; and Yates et al. 2009). Additionally, it has watershed rainfall-runoff modeling capabilities that allow all portions of the water infrastructure and demand to be dynamically nested within the underlying hydrological processes. This functionality allows the analyses of how specific configurations of infrastructure, operating rules, and operational priorities will affect water uses as diverse as instream flows, irrigated agriculture, and municipal water supply under the umbrella of input weather data and physical watershed conditions. This integration of watershed hydrology with a water systems planning model makes WEAP ideally suited to study the potential impacts of climate change and other uncertainties internal to watersheds. The physical water management system represented in WEAP is represented conceptually below.



Box 5-5 Water Footprint as an Index of Sustainability

The California Water Plan includes California's Water Footprint as a broad index of demand for water resources by the people of California. The State's water footprint is a measure of the total volume of freshwater that is used to produce the goods and services consumed by Californians. This water use is measured in terms of the volume of water consumed (i.e., evaporated or incorporated into a product) in a given year. The water footprint has an internal and external component. The internal water footprint is the water required to make the goods that are produced and consumed within California, as well as the direct use of water inside the state. The external water footprint includes the water required to make goods in other places that are then imported and consumed in the state.

Monitoring how California's Water Footprint has changed over time can help planners understand how the state's water resources are being used, as well as how its population is being supported by both internal and external water resources. As shown in Figure A, California's Water Footprint has changed dramatically over the past two decades. During this period, the water footprint has increased by nearly 40 million acre feet (maf) per year, from about 60 maf in 1992 to 100 maf in 2010. During this period, California's internal water footprint has declined, while the external water footprint has grown dramatically, suggesting that the state has become increasingly reliant on external water resources. In addition, California's water resources have been increasingly devoted to products that are exported and consumed outside of the state.

Water footprint assessments address the complex ways in which humans interact with natural systems, such as the water cycle. Much of this complexity has to do with the global nature of California's economy, where goods and services are traded across regions, states, and among distant countries. So, for Californians, the goods and services we consume might be produced in many different places around the world. Thus, California affects and is affected by water resource conditions in other countries and other parts of the United States. A change in water availability elsewhere could affect not only California's economy, but also the way water is used here. The California Water Sustainability Indicators Framework definition of sustainability therefore implies a need to recognize water use not only within California but also in locations from where the products consumed in California are produced. The Water Footprint index helps address this complex task in a systematic way and may be used to address important issues related to sustainable water use in the state. For more information on California's Water Footprint, see the Volume 4 article and the 2012 report by the Pacific Institute, "California's Water Footprint," http://www.pacinst.org/publication/assessment-of-californias-water-footprint/.

PLACEHOLDER Figure A Changes in California's Water Footprint

Figure A Changes in California's Water Footprint